NPS-LM-13-087

ACQUISITION RESEARCH PROGRAM SPONSORED REPORT SERIES

Cost Reduction Through the Use of Additive Manufacturing (3D Printing) and Collaborative Product Lifecycle Management Technologies to Enhance the Navy's Maintenance Programs

30 August 2013

LCDR Michael E. Kenney, USN

Thesis Advisor: Dr. Thomas Housel, Professor
Second Reader: Dr. Johnathan Mun, Professor

Graduate School of Operational & Information Sciences

Naval Postgraduate School

Prepared for the Naval Postgraduate School, Monterey, CA 93943.

<table>
<tr><td colspan="4">Report Documentation Page</td><td colspan="2">Form Approved
OMB No. 0704-0188</td></tr>
<tr><td colspan="6">Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.</td></tr>
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30 AUG 2013</td><td colspan="2">2. REPORT TYPE</td><td colspan="2">3. DATES COVERED
00-00-2013 to 00-00-2013</td></tr>
<tr><td colspan="4" rowspan="3">4. TITLE AND SUBTITLE
Cost Reduction Through the Use of Additive Manufacturing (3D Printing) and Collaborative Product Lifecycle Management Technologies to Enhance the Navy’s Maintenance Programs</td><td colspan="2">5a. CONTRACT NUMBER</td></tr>
<tr><td colspan="2">5b. GRANT NUMBER</td></tr>
<tr><td colspan="2">5c. PROGRAM ELEMENT NUMBER</td></tr>
<tr><td colspan="4" rowspan="3">6. AUTHOR(S)</td><td colspan="2">5d. PROJECT NUMBER</td></tr>
<tr><td colspan="2">5e. TASK NUMBER</td></tr>
<tr><td colspan="2">5f. WORK UNIT NUMBER</td></tr>
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Naval Postgraduate School,Graduate School of Business & Public Policy,Monterey,CA,93943</td><td colspan="2">8. PERFORMING ORGANIZATION REPORT NUMBER</td></tr>
<tr><td colspan="4" rowspan="2">9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)</td><td colspan="2">10. SPONSOR/MONITOR’S ACRONYM(S)</td></tr>
<tr><td colspan="2">11. SPONSOR/MONITOR’S REPORT NUMBER(S)</td></tr>
<tr><td colspan="6">12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited</td></tr>
<tr><td colspan="6">13. SUPPLEMENTARY NOTES</td></tr>
<tr><td colspan="6">14. ABSTRACT
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<tr><td colspan="3">16. SECURITY CLASSIFICATION OF:</td><td rowspan="2">17. LIMITATION OF ABSTRACT
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75</td><td rowspan="2">19a. NAME OF RESPONSIBLE PERSON</td></tr>
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The research presented in this report was supported by the Acquisition Research Program of the Graduate School of Business & Public Policy at the Naval Postgraduate School.

ABSTRACT

In order to keep its ships and aircraft in an operational status, the U.S. Navy must have access to the parts necessary for repair. Current supply warehouses do not always carry the required repair parts; therefore, when parts are unavailable, the Navy must either look to traditional acquisition sources or utilize manufacturing capabilities available at depot and intermediate maintenance activities.

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ACKNOWLEDGMENTS

The process of doing the work involved in this research could not have been done without the assistance of some very important people whom I wish to thank. First and foremost, I thank my wife, Kathleen, for allowing me to take these orders for shore duty at the Naval Postgraduate School and for being there to endure my endless discussions about my research. Next, I want to thank Dr. Thomas Housel for his support and guidance during the thesis process. I also want to thank Glenn Cook, Albert Barreto, and Dr. Johnathan Mun for their time and support in assisting in my research.

This work would not have been possible without the assistance of the many subject-matter experts from Naval Sea Systems Command and several fleet readiness centers. The time they spent outside of their work in order to provide information and understanding about Navy maintenance was critical to this research, and I want to thank them for their assistance. Next, I want to thank Tera Yoder, Karey Shaffer, and Jim Greene of the Acquisition Research Program for their outstanding support and guidance. Finally, I want to thank my cohorts within the Information Systems Technology program. These outstanding gentlemen were my sounding wall and bearing check throughout this academic program and, I have to say, some of the finest shipmates I have had the pleasure of serving with during my two decades of naval service.

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ABOUT THE AUTHORS

LCDR Michael Kenney is a full time support (FTS) surface warfare officer. Initially enlisting in 1992, LCDR Kenney served four years in the electronics technician and fire controlman rates before being accepted for a NROTC scholarship to Oregon State University. After earning a Bachelor of Science in economics in 2000 and his commission, LCDR Kenney served his Division Officer tours on board USS *Fife* (DD 991) and USS *Donald Cook* (DDG 75). Upon completion of his Division Officer tours, he took command of Navy Operational Support Center Fort Richardson, located outside of Anchorage, Alaska. After a successful shore assignment and Department Head tours, as weapons and combat systems officer on board USS *Halsey* (DDG 97), LCDR Kenney reported to Naval Postgraduate School (NPS) in pursuit of a Master of Science in information technology management. Upon graduation from NPS, he will be reporting to OPNAV 0956 to work for the Chief of Navy Reserve in the Deputy Chief Information Officer billet.

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LIST OF ACRONYMS AND ABBREVIATIONS

2D	Two-Dimensional
3D	Three-Dimensional
AIMD	Aircraft Intermediate Maintenance Department
ALT	Actual Learning Time
AM	Additive Manufacturing
B	Basic Rate
CAD	Computer-Aided Design
CNC	Computer Numerical Control
CPLM	Collaborative Product Lifecycle Management
D-Level	Depot Level
DDG	Guided Missile Destroyer
DLA	Defense Logistics Agency
DoD	Department of Defense
DoN	Department of the Navy
DOP	Specified Overhaul Point
FAA	Federal Aviation Administration
FRC	Fleet Readiness Center
FY	Fiscal Year
GS	General Schedule
HT	Hull Technician
I-Level	Intermediate Level
IMA	Intermediate Maintenance Activity
IT	Information Technology
KVA	Knowledge Value Added
MR	Machinery Repairman
NAVAIR	Naval Air Systems Command
NAVSEA	Naval Sea Systems Command
NEC	Navy-Enlisted Classification
NSWC	Naval Service Warfare Center
O-Level	Organizational Level
OEM	Original Equipment Manufacturer
OER	Original Equipment Representative
OJT	On-the-Job Training
PLM	Product Lifecycle Management
QA	Quality Assurance
RLT	Relative Learn Time
ROI	Return on Investment
ROK	Return on Knowledge
SIMA	Shore Intermediate Maintenance Activity
SME	Subject-Matter Expert
STL	Stereolithography
TLC	Technology Life Cycle
TLT	Total Learning Time
WG	Wage Grade

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I. INTRODUCTION

A. BACKGROUND

The United States Navy needs to keep its ships and aircraft in good working order in order to meet the operational requirements that civilian leadership has mandated. When one of these units becomes unavailable for operational assignments, the priority is on getting broken parts replaced and the unit back into operational status; otherwise, the unit cannot serve its purpose for the American taxpayer. In order for a repair part to be supplied to the affected unit, it needs to be issued by the Defense Logistics Agency (DLA) via the Navy supply system. If the part is not available from the warehouse's shelves, then the DLA needs to acquire it by utilizing the traditional acquisition system or by having the part made or repaired by a Navy maintenance facility. This thesis is built on previous research conducted by Nathan Seaman (2006) and Christine Komoroski (2005). Their work measured the outcome of introducing new information technology (IT) in the form of three-dimensional (3D) terrestrial laser scanning and product lifecycle management (PLM) into the United States Navy public-sector maintenance planning yards. Komoroski's (2005) research showed that by including these technologies, total product costs decreased by 89%. Given the increased visibility of additive manufacturing (AM), also known as 3D printing, and its inclusion into current private-sector industries for the manufacturing of parts and the creation of prototypes, this research builds on previous work to see if this technology can further decrease costs within the Navy maintenance program.

Maintenance and upkeep is paramount for the armed services. With the need to maintain equipment such as ships, aircraft, and vehicles, each service supports the operational requirements set forth by the civilian leadership of the U.S. government. The amount of budget resources committed to maintaining equipment in good operational condition is significant. In addition to the responsibility placed on Department of Defense (DoD) leadership to be good stewards of the American taxpayer's dollar, there is also the need to find effective cost reduction due to budgetary constraints imposed by continuing resolutions. In fiscal year (FY) 2011, the DoD allocated $83 billion (12%) of its $608 billion budget to support 283 ships, 13,900 aircraft, 800 strategic missiles, and 311,000 tactical vehicles (Office of the Deputy Under Secretary of Defense [Logistics and Materiel

Readiness], 2012). FY2012 actual numbers from the undersecretary of defense comptroller showed that the Navy spent a total of $9.1 billion on maintenance activities: $7.1 billion for ship maintenance, $1.17 billion for depot-level (D-level) operations, and $972 million for intermediate-level (I-Level) operations. These maintenance activities supported more than 286 deployable battle-force ships and 3,700 operational aircraft (Department of the Navy [DoN], 2013b) via 47 ships and shore depots and eight I-Level maintenance activities (DoD, 2011).

B. RESEARCH OBJECTIVES

Extending Seaman's (2006) and Komorski's (2005) research, the current research attempts to show whether the adoption of AM technology can provide additional cost savings and reduction to the overall cycle time associated with D-Level and I-Level repairs to operational assets. An as-is analysis includes the D-Level replacement-part processes currently in place in order to create reliable knowledge value added (KVA) outputs for return on knowledge (ROK) and return on investment (ROI) estimates. From this baseline, the process is reconfigured to allow for the introduction of AM and collaborative product lifecycle management (CPLM) software as to-be and radical to-be models in order to evaluate potential cost savings.

C. RESEARCH QUESTIONS

This research attempts to answer the following questions regarding the introduction of new technology into Navy maintenance:

- Is AM a viable technology that can provide repair-part creation and improve overall aircraft and ship maintenance processes?
- Can AM be quickly incorporated into the various Navy maintenance levels in order to provide replacement-part production that improves overall operational support, thereby increasing readiness?
- Does the introduction of AM and CPLM increase value and lower cost in aircraft and ship maintenance?

D. METHODOLOGY

This thesis utilizes data collected from Navy subject-matter experts (SMEs) at D-Level maintenance activities. KVA modeling is used similarly to the way it was used in the Seaman (2006) and Komoroski (2005) studies: to measure the impact of AM and CPLM

software on the current as-is process model. SMEs validated the process model, which includes estimates of each process and subprocess learning times, number of personnel, and how often the process was conducted. Comparisons to the private sector are included in order to extrapolate estimations of cost and the value added to these technologies.

E. SCOPE

This thesis utilizes KVA to generate ROK and ROI estimates resulting from the inclusion of AM and CPLM tools into the Navy's D-Level maintenance processes. It was expected that these technologies would provide additional cost savings. However, it needs to be noted that the scope of this research is limited to D-Level maintenance activities and does not take into full consideration intermediate and organizational maintenance levels. This means that in reference to the overall maintenance program of the Navy, this research covers only a portion of the potential that these technologies have to offer with respect to cost savings.

F. ORGANIZATION OF THESIS

Chapter I included an overview of the research and identified the primary objective, focus questions, and methodology. Chapter II reviews applicable literature about Navy maintenance levels, the technology of AM, CPLM software, and KVA. Chapter III reviews the KVA methodology as utilized in Seaman's (2006) and Komoroski's (2005) research and explains, with references, how the methodology is used to calculate the data obtained from SMEs. Chapter IV describes a nominal D-Level maintenance process for the creation of repair parts and identifies underlying assumptions for the KVA models. The chapter also applies the KVA methodology outlined in Chapter III with respect to as-is, to-be, and radical to-be scenarios in order to estimate ROK and ROI values. Chapter IV also includes the analysis of the results. Chapter V concludes with interpretations of the findings from Chapter IV and suggests future research possibilities.

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II. LITERATURE REVIEW

A. INTRODUCTION

The purpose of this chapter is to initiate discussion about what AM and CPLM technologies are in order to determine potential cost savings and other benefits that they may offer to the Navy maintenance program. First, the Navy's traditional acquisition of spare parts is explained with respect to how it can hinder repair of operational units due to long lag times. This lag time decreases overall operational capability. Then, the Navy's maintenance levels are explained in order to show, in their hierarchy, how the Navy expects maintenance to be performed at a particular maintenance level and by whom. Next, a technical review of AM is provided to show what its capabilities are (as of 2013) in order to provide an improved understanding of where this technology stands in relation to a nominal technology life cycle. From there, the process of AM part generation is discussed to improve the reader's understanding of the necessary steps and the expected outputs of AM. This discussion also provides the foundation for the assumptions used to calculate KVA estimates. Finally, the inclusion of CPLM software into maintenance activities is reviewed to further improve communications between stakeholders in terms of the added benefit that it brings towards increased productivity and innovation.

B. ACQUISITION

To put it simply, when a ship or aircraft is no longer fully operational due to a problem caused by a faulty part or piece of equipment, the unit's maintenance person turns the part carcass over to the supply system for issuance of a new repair part. Supply either provides a new part or has to requisition for a new part to be ordered. If the part is no longer available within the stock system, the DLA goes to the parent company of the piece of equipment to acquire the part. If the parent company no longer exists or does not make the part anymore, then the DLA has to proceed with finding vendors from the private sector and contract out to a winning bidder to have the part made. However, if the part can be produced from a Navy maintenance activity, then the DLA, via the Navy supply system, can exercise the option to have the repair part made only after exhausting its options. From here, the

activity, utilizing the manufacturing materials located on site, builds the part and provides it back to the supply system for delivery to the customer.

C. NAVY MAINTENANCE LEVELS

In 2011, the Navy employed more than 181,000 military and civilian maintainers, 27.6% of total DoD maintainers, distributed throughout its maintenance activities, as shown in Figure 1.

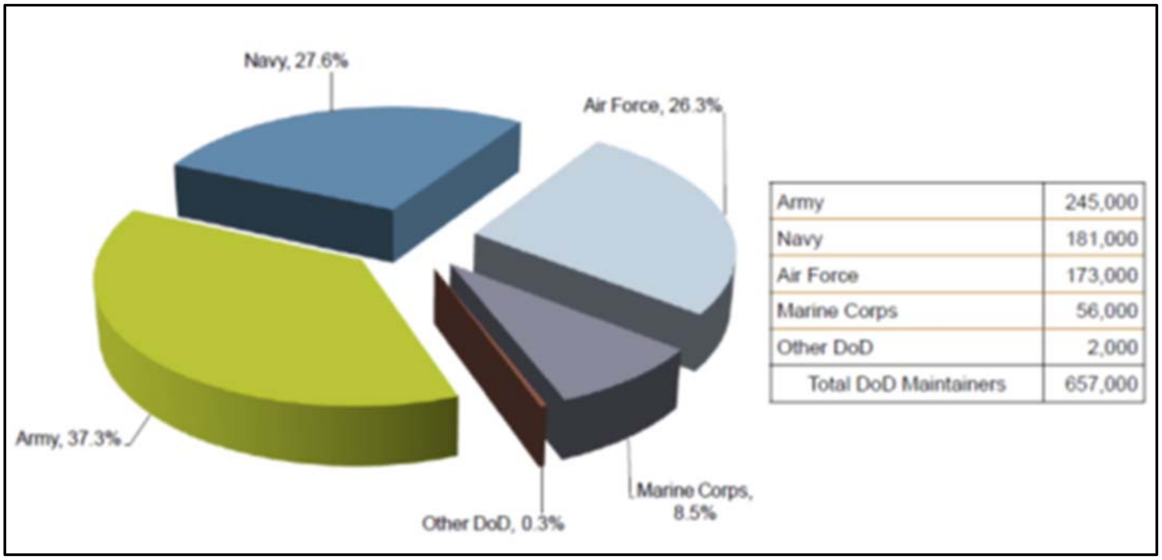

Figure 1. DoD Breakdown of Maintainers
(DoD, 2011)

The amount of manpower required to support the overall goal of the Navy's maintenance program, which, according to Office of the Chief of Naval Operations Instruction (OPNAVINST) 4700.7L, is to "maintain the highest practical level of materiel readiness and safety to meet the required area of operation's need while minimizing total life-cycle cost over the expected life of asset (ship, aircraft, submarine)" (Chief of Naval Operations [CNO], 2010, p. 6). This goal is supported by the Navy's identification and creation of specific maintenance levels with assigned roles and responsibilities. These levels are identified as organizational, intermediate, and depot levels of maintenance. Figure 2 shows that given the level of maintenance, the scope of work, skill level required, and complexity of the repair is relative to the expected outcome of that activity, as described by the *DoD Maintenance Fact Book* (DoD, 2011).

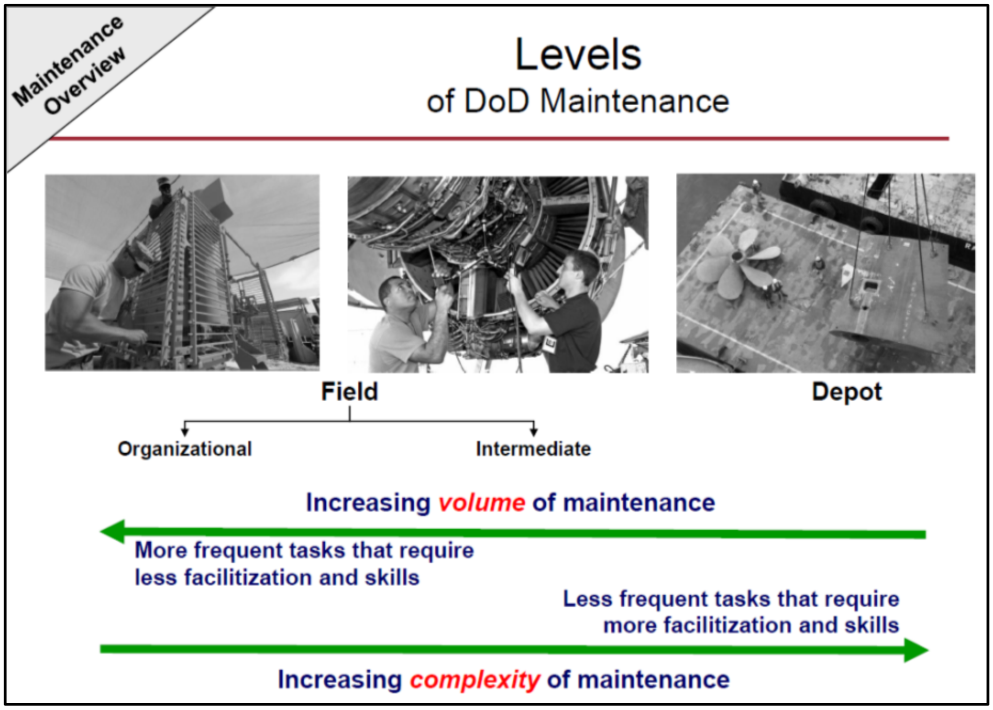

Figure 2. Levels of DoD Maintenance
(DoD, 2011)

Figure 3 is an interpretation of the technician's expected skill level, the complexity of work, and the aggregate scope of work that each DoD maintenance level encompasses.

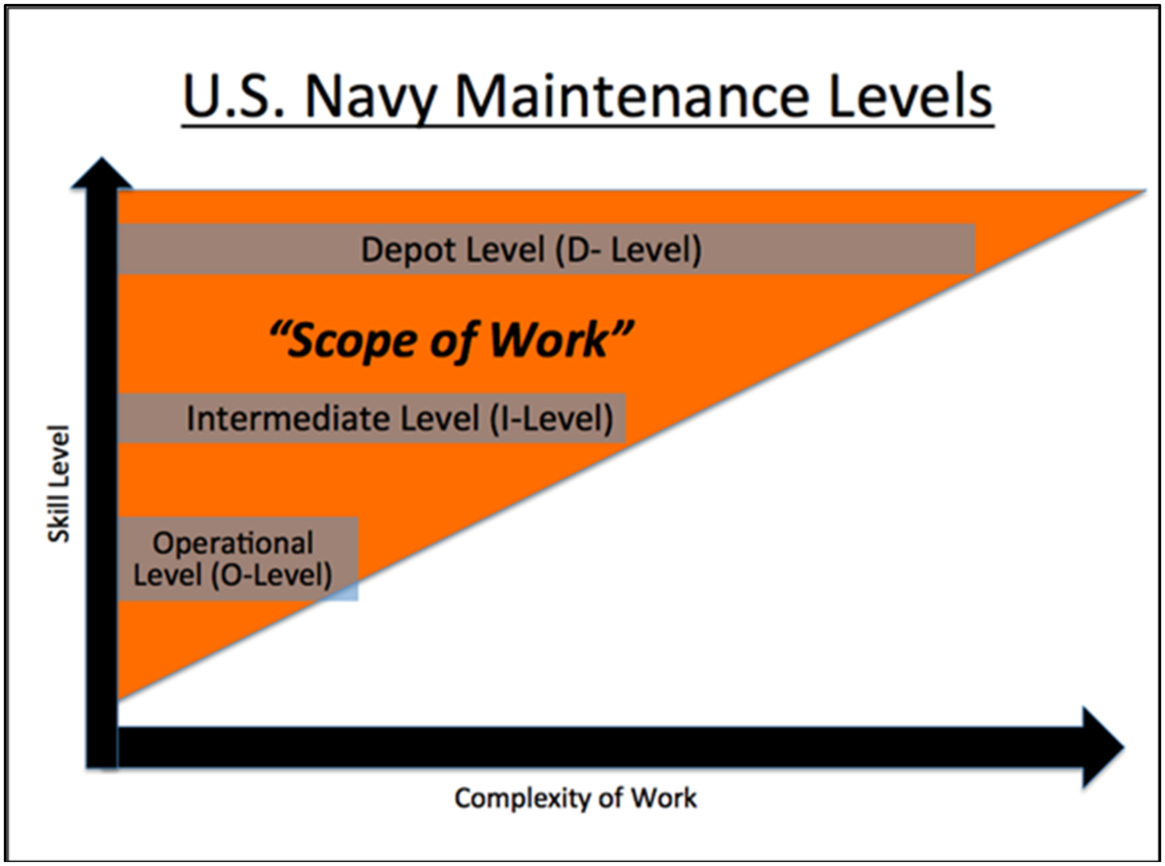

Figure 3. U.S. Navy Maintenance Levels

1. Organizational-Level Maintenance

Organizational-level (O-Level) maintenance is maintenance that is performed by Navy personnel within the organization who hold responsibility for the maintenance being accomplished (CNO, 2013). O-Level maintenance is the lowest maintenance level and is the first defense against allowing small issues to escalate into significant operational and material problems (CNO, 2010). According to the chief of naval operations (2010), typical O-Level maintenance includes the following:

- routine systems and components planned maintenance,
- corrective maintenance, and
- assistance to higher level maintenance activities.

The ability to create spare parts at the O-Level is very limited due to the lack of tooling, machinery, raw materials, and skill. For example, an Arleigh Burke guided missile destroyer (DDG) is equipped with one machine shop populated with basic part fabrication tooling (lathe, drill press, sheet metal equipment, welders). The four to six personnel that make up

the machine shop include the Navy's hull technician (HT) and machinery repairman (MR) rates. All of these Sailors possess only the initial level training from A-Schools, which is provided to them following basic training, with the exception of one or two Sailors who possess a Navy-enlisted classification (NEC) code advanced school.

2. Intermediate-Level Maintenance

I-Level maintenance is maintenance that is made up of Navy personnel and/or civilians, performed for operational units, and carried out within shore intermediate maintenance activities (SIMAs), aircraft carriers, fleet support bases, or tenders (CNO, 2013). I-Level activities require skills, facilities, and capabilities that are higher in scope than that of the O-Level but at a level below that of a D-Level (CNO, 2010). According to the chief of naval operations (2010), typical I-Level maintenance includes the following:

- installation of alterations,
- higher level preventative and corrective maintenance beyond the capabilities of O-Level facilities and resources,
- technical assistance to O-Level in diagnosing system or equipment issues, and
- work on equipment that is used as rotational assets.

I-Level maintenance activities have a greater ability to generate repair parts than O-Level maintenance activities due to the increased amount of skilled personnel, machinery and manufacturing capability, and on-demand knowledge base resources. The I-Level is the first level that can contract to outside resources for the manufacturing of parts and services. However, the ability to design and engineer a spare part is limited due to the required skill level required of I-Level maintenance.

3. Depot-Level Maintenance

D-Level maintenance is maintenance conducted by industrial activities that involves major overhaul, the manufacturing of parts, system modifications, testing, and reclamation (CNO, 2013). The degree of skill, facilities, and capacity required at the D-Level needs to be beyond that of O-Level and I-Level activities (CNO, 2010). D-Level maintenance activities

include Navy shipyards, private shipyards, original equipment representatives (OERs), or specified overhaul points (DOP) designated by Naval Sea Systems Command (NAVSEA; CNO, 2010).

Table 1 summarizes the breakdown of each maintenance activity by personnel, complexity, and scope of work.

Table 1. Navy Maintenance Activity Breakdown

	Personnel	Scope of Work	Complexity of Work
Organizational Level	Military	Low	Low
Intermediate Level	Military and Civilian	Medium	Medium
Depot Level	Civilian	High	High

D. ADDITIVE MANUFACTURING

AM, more commonly known as 3D printing, is a process of creating a three-dimensional object or model from a digital model. Using an AM machine, or printer, successive layers of material are laid down in arranged patterns and lines in accordance with the digital design. The uses of AM vary and can be found in the areas of industry described in Table 2 (http://www.stratasys.com/).

Table 2. Additive Manufacturing in Industry (Stratasys, 2013)

Industry	Companies/Organizations	Uses
Aerospace	General Electric, ACS, Bell Helicopter, Boeing, NASA	Wire conduit, Unmanned aircraft (UAV) parts, Mars Rover
Automotive	BMW, Lamborghini, Hyundai, Land Rover	Design verification, development
Defense	Army, Air Force, Marines, Navy	Tooling, template construction, prototyping, new part manufacture
Medical	UCLA Medical Center, Medtronic, Script Pro	Prosthetics, design, prototyping

Rapid prototyping is a term that is often used when referring to AM, but in fact, it refers to a group of processes that generate prototypes quickly, to include AM, formative manufacturing, and subtractive manufacturing. Figure 4 represents a holistic representation of rapid prototyping.

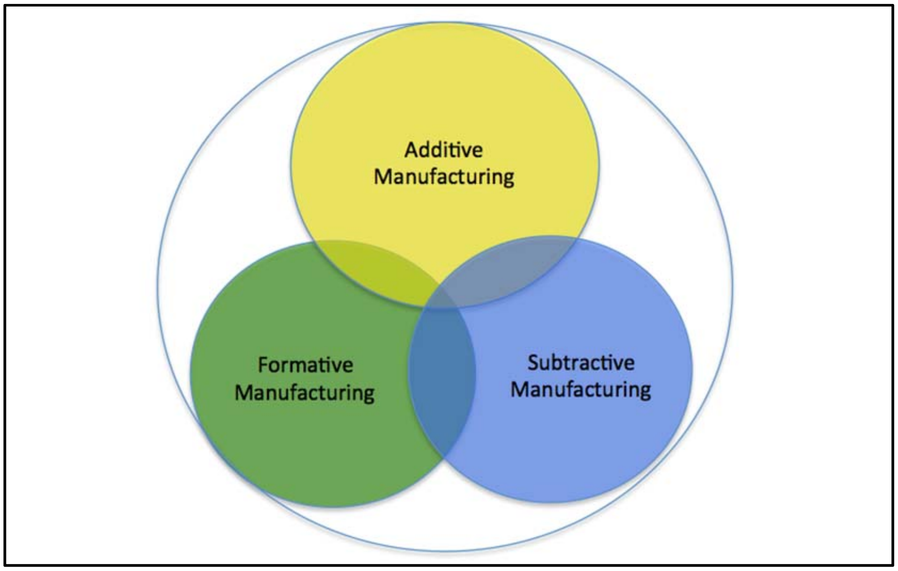

Figure 4. Rapid Prototyping
(Grimm, 2004)

In short, the definition of *rapid prototyping* is a collection of technologies that are driven by computer-aided design (CAD) data to produce physical models and parts through one of the previously mentioned manufacturing processes; the result is the completion of a process faster than that which was previously possible (Grimm, 2004). The advantage of rapid prototyping is that it can be utilized as a tool to improve communication by showing to all members involved in a process (e.g., decision-makers, engineers, machinists, manufacturers) what the final product will be (Grimm, 2004). This communication enables members to plan, coordinate, and provide feedback on the product's creation. When a design takes physical form, ambiguity, assumptions, and perceptions are eliminated from the manufacturing process, and validation of the product will occur (Grimm, 2004).

Subtractive manufacturing refers to the manufacturing process that removes material from a block or product base, utilizing either a drill or cutting device. A common subtractive manufacturing device is a computer numerical control (CNC) machine. Formative manufacturing utilizes molds or other similar templates; liquefied material is poured or injected into the mold, resulting in a product.

AM industry is a growing industry with many companies that offer differing processes for a variety of markets. Table 3 shows the different processes, examples of

companies that build machines for that process, the materials used in the machines, and the applicable markets.

Table 3. Additive Manufacturing Processes, Associated Companies, and Markets (Scott et al., 2012)

Process	Example Companies	Materials	Market
Vat Photopolymerization	Photopolymerization 3D Systems (US), Envisiontec (Germany)	Photopolymers	Prototyping
Material Jetting	Objet (Israel), 3D Systems (US), Solidscape (US)	Polymers, Waxes	Prototyping Casting Patterns
Binder Jetting	3D Systems (US), ExOne (US), Voxeljet (Germany)	Polymers, Metals, Foundry Sand	Prototyping, Casting Molds, Direct Part
Material Extrusion	Stratasys (US), Bits from Bytes, RepRap Polymers Prototyping EOS (Germany),	Polymers	Prototyping
Powder Bed Fusion	3D Systems (US), Arcam (Sweden)	Polymers, Metals	Prototyping, Direct Part
Sheet Lamination	Fabrisonic (US), Mcor (Ireland)	Paper, Metals	Prototyping, Direct Part
Directed Energy Deposition	Optomec (US), POM (US)	Metals	Repair, Direct Part

There are several technologies available for construction using AM. Table 4 displays the types, machines, and materials used in AM.

Table 4. Additive Manufacturing Types, Machines, and Materials

Type of Additive Manufacturing	Additive Manufacturing Machines	Additive Material Used
Extrusion	Fused deposition modeling (FDM)	Thermoplastics (e.g., PLA, ABS), HDPE, eutectic metals, edible materials
Granular	Direct metal laser sintering (DMLS)	Most metal alloys
	Electron beam melting (EBM)	Titanium alloys
	Selective laser melting (SLM)	Titanium alloys, cobalt chrome alloys, stainless steel, aluminum
	Selective heat sintering (SHS)	Thermoplastic powder
	Selective laser sintering (SLS)	Thermoplastics, metal powders, ceramic powders
Laminated	Laminated object manufacturing (LOM)	Paper, metal foil, plastic film
Light Polymerized	Stereolithography apparatus (SLA)	Photopolymer
	Digital light processing (DLP)	Photopolymer
Powder bed and inkjet head 3D printing	Plaster-based 3D printing (PP)	Plaster
Wire	Electron beam freeform fabrication (EBF)	Most metal alloys

1. Additive Manufacturing Process

AM is a more complex operation than what may be perceived. It includes more than just loading up a 3D file from a CAD system, pushing a button, and obtaining a finished product. Given the different types of AM processes displayed in Table 4, there is a general commonality associated with the workflow for the production of rapid prototypes. Utilizing what Grimm (2004) discussed regarding the workflow, and adding in the design of a product, the following six steps for AM generally occur:

- product design using CAD,
- stereolithography (STL) file generation,
- file verification and repair,
- file creation,
- part construction, and
- part cleaning and finishing.

This process is a general, macro view of how to create a part using AM machines and does not go into the minute specifics that would be involved with all products. Each type of AM

machine and the material it uses in order to create an end product has its own characteristics that are specific to itself.

a. Computer-Aided Design Creation

CAD refers to an application that can represent physical products by using math-based, triangular descriptions in order to locate and replicate shapes in either two or three dimensions (Schindler, 2010). 3D models created using CAD (see Figure 5) enable improvements to quality and reduce overall developmental time and costs by creating a model that is precise, easily replicated, and easily conceptualized because the object can be rotated and displayed from multiple views (Schindler, 2010).

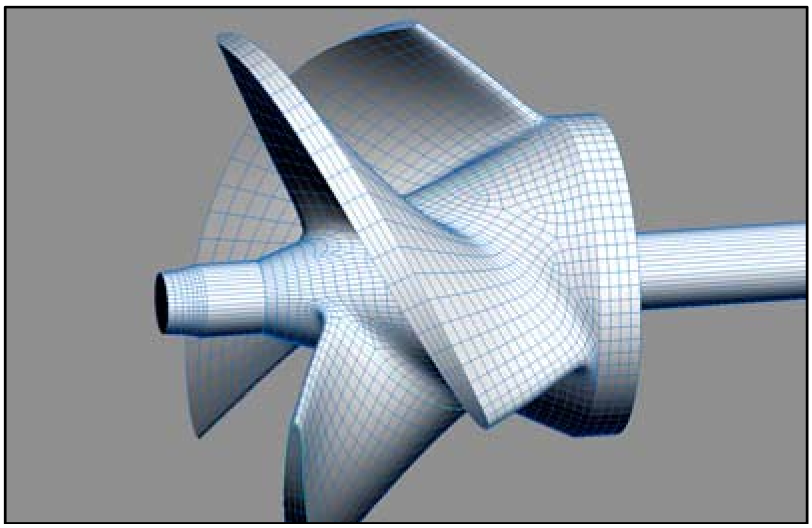

Figure 5. 3D Computer-Aided Design of a Ship's Propeller
(Solid-Ideas, 2011)

For AM, CAD models, when complete, are transferred into STL files. STL files are 3D digital data of the product that provide the data required for an AM machine. The STL file is a neutral file format designed in order to utilize any CAD system to feed the required data into the AM machine (Grimm, 2004). From there, the STL file uses a simple triangular mesh that approximates the total amount of surface of the part. The overall goal of the STL file is to create a balanced model quality and file size by dictating the allowable deviation between the model's surface and the face of the triangle (Grimm, 2004).

b. File Verification and Repair

CAD models and STL generation can possess errors that may affect the total quality of the end product. During this step, associated STL software verification programs analyze the file for defects and then provide an output for the operator to determine whether the STL file is usable (Grimm, 2004). Utilizing an STL repair program, the majority of defects can be corrected; however, in some cases, it becomes necessary to send the file back to design in order to correct errors. Returning the file back to the design stage is often associated with poor CAD modeling techniques (Grimm, 2004).

c. Build File Creation

This section of AM prototype generation involves four steps: part orientation, support structure generation, part placement, and build file creation. Part orientation is a critical step with respect to the amount of time it takes to build a prototype. In AM, the axis of an object is built using a coordinate 3D scale in which *x* and *y* represent length and width, respectively, and *z* represents height (see Figure 6); as the height increases, so does the build time (Grimm, 2004).

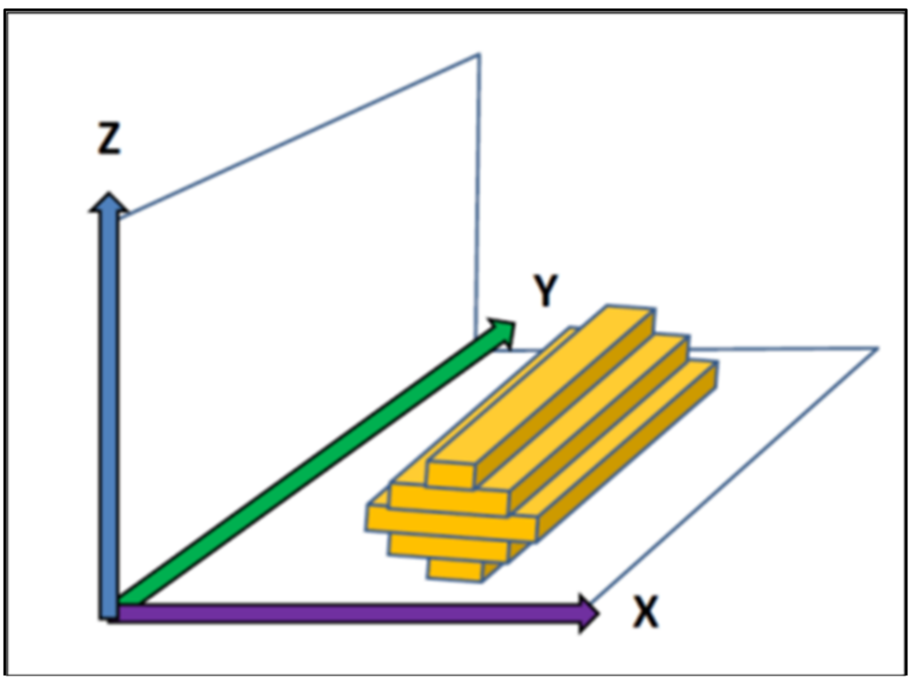

Figure 6. 3D Coordinates for Additive Manufacturing

If a prototype's purpose is to be used as a template or pattern, the need to reduce the amount of "stair stepping" in order to create a smoother surface requires a greater amount of time. Stair stepping is an effect created during AM when successive layers of material are added on to one another, forming stair-like ridges. This effect is reduced by reducing the thickness of the material being applied and results in a smoother surface (Grimm, 2004). When considering the design of a prototype, the designer needs to take into account a balance between time and quality: a prototype or part built vertically yields a higher quality product but takes more time; however, if quality is not the priority because the goal is just to communicate the concept to the actors involved, then the part should be built horizontally, which reduces the overall build time.

Given the type of material being used in AM, support structures are needed in the production of the prototype or part. Support structures are very important in the manufacturing to prevent shifting and reduce or eliminate the amount of sagging or slumping of features (Grimm, 2004). Supports provide rigid attachment to the build platen (base support structure) and provide support to any overhanging geometry (Grimm, 2004).

AM possesses the capability to create multiple parts simultaneously as long as they are properly laid out within the build envelope. The efficient use of a build envelope reduces the total time and cost (Grimm, 2004).

d. Part Construction

During the part construction phase of AM, the creation of the part is conducted at the machine. AM machines, for the most part, operate 24 hours a day without human intervention, making this a significant advantage in the cost of labor. The only labor involved with part construction is the machine preparation, build launch, and removal of the prototypes upon completion (Grimm, 2004).

e. Part Cleaning and Finishing

Cleaning of the part is the most manual, labor-intensive portion of the AM process (Grimm, 2004). During this phase, the part is not yet ready to be used and may need to have excess material or support structures removed. Also, based on the type of AM machine involved, the type of material used may require other processes and machinery for cleaning and finishing (Grimm, 2004).

2. Technology Life Cycle

IT plays an important, if not vital, role in industrial and manufacturing organizations (Costa & Aparicio, 2007). In the case of AM, it is important to understand where AM currently is with the technology life cycle (TLC). The TLC demonstrates the commercial gain of a product via its life-cycle phases. It is primarily concerned with the overall time and cost needed to develop a technology, the amount of time needed to recover the cost of developing a technology, and the process of making a technology yield a profit proportionate to the costs and risks involved (Costa & Aparicio, 2007). Figure 7 displays a nominal TLC path.

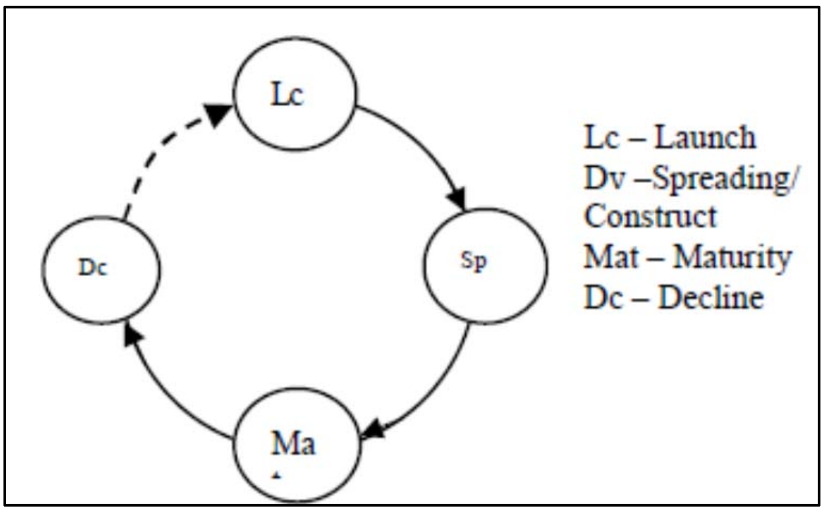

Figure 7. Technology Life-Cycle Path
(Costa & Aparicio, 2007)

With each of the phases of TLC, there are associated technology, operations, and costs. Table 5 explains these aspects.

Table 5. Aspects of Technology Life-Cycle Phases (Costa & Aparicio, 2007)

Role Versus Technological, Operational, and Economical Dimensions			
	Technology	Operation	Costs
Launch	Identify technologies that may answer to strategies, and obtain in-depth knowledge of the technology adopted.	Identify strategies, motivate future sponsors of the systems, identify the needs, and focus on the implementation of the system and not on marginal items.	Look into expenses and all their dimensions (e.g., investments, maintenance costs, or training); and control costs, quality, and execution time.
Spreading	First signs of good integration of the system with other subsystems.	Maintain good services and maintenance in order to contribute to high productivity in the organization, and make other employees productive.	Costs are still high in order to expand and contribute the maximum productivity.
Maturity	Still adequate integration of system with the operations of the organization.	The maximization of the benefits has been achieved and there is a balance between the contributions of the system and efforts to make the implementation happen.	Reduce costs, emphasize the maintenance and service agreements, and carefully analyze the tradeoff between do and buy.
Decline	Identify applications, technologies, software, and hardware compatible with the technologies used by the organization.	Train and educate users to the change.	Try to profit from the legacy system, and try to move to new applications.

With regard to AM, Terry Wohlers and Tim Caffrey (2013) stated in a Society of Manufacturing Engineers (SME) journal article that “it is important to point out where the technology is and where it is going” (p. 1). The fastest growing application for AM is part

manufacturing and prototyping, although its potential is still not fully understood or utilized (Wohlers & Caffrey, 2013). Assessment from within the industry shows that AM is still within the "spreading/construct" phase of its life cycle, proceeding towards maturity.

E. COLLABORATIVE PRODUCT LIFECYCLE MANAGEMENT

1. Product Lifecycle Management Definition

CPLM is a business approach that can align and increase the overall efficiency and effectiveness of individual activities by utilizing software applications and leveraging process improvements (Schindler, 2010). Its ability to be utilized as a strategy instead of a system enables product lifecycle management (PLM) to be configured in a manner that addresses the unique aspect of an organization. The result is that an organization is able to address its particular requirements, identify strengths and weaknesses, and invest in capital applicable to its needs. CIMdata (n.d.) defined *PLM* (Product Lifecycle Management, n.d.) as follows:

- a strategic business approach that applies a consistent set of business solutions that support the collaborative creation, management, dissemination, and use of product definition information;
- supporting the extended enterprise (customers, design and supply partners, etc.);
- spanning from concept to end of life of a product or plant; and
- integrating people, processes, business systems, and information.

It is important to note that PLM is not a piece, or pieces, of technology. It is a business approach to solving the problem of managing the complete set of product definition information—creating that information, managing it through its life, and disseminating and using it throughout the life cycle of the product. PLM is also an approach in which processes are as important, or more important, than data. It is critical to note that PLM is as concerned with "how a business works" as with "what is being created" (CIMdata, n.d.). Figure 8 displays PLM across the life cycle of a product.

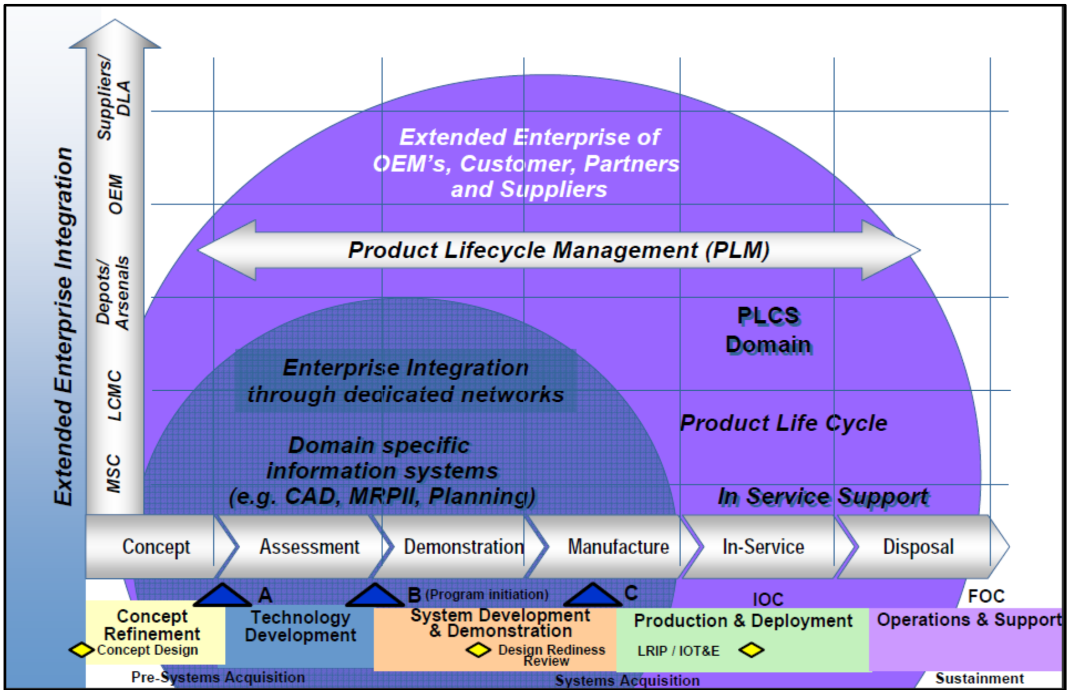

Figure 8. Collaborative Product Lifecycle Management Across the Life Cycle
(Schindler, 2010).

PLM software supports a broad range of products that include manufactured items like computers, automobiles, software, and public utilities (e.g., gas, water, power) that need to be organized and managed (CIMdata, n.d.). The software integrates people, data processes, and business systems while providing opportunities for activities to exchange information with their enterprise. In addition, implementing PLM allows activities to build on and optimize products by increasing collaboration, resulting in reductions in costs (Schindler, 2010).

2. Increased Productivity

The Navy is similar to the corporate world in that it needs to create value and find ways to improve productivity, innovation, collaboration, and quality in order to maintain a competitive edge (Grieves, 2006). *Productivity*, according to Schindler (2010), refers to the ratio of output (quantity of goods or services produced by a firm or industry in a given time period) compared to input (the amount of resources or cost to produce the good or provide the service). In the corporate world, this output translates to profit. For the Navy, where there is no profit generated, productivity is still critical when vying for available budget

dollars and by optimizing funds that are available (Schindler, 2010). Introducing CPLM provides the ability to directly increase productivity by providing "as needed" information to users at the right time, thereby eliminating time wasted searching for data and recreating designs (Schindler, 2010).

3. Increased Innovation

Innovation is a change in a group's thought process in doing something and can be referred to as radical, revolutionary, emergent, or incremental changes to thinking, production, or processes (Schindler, 2010). Grieves (2006) stated that "productivity focuses on costs, while innovation focuses on adding value for the stakeholder" (p. 24). Furthermore, he pointed out that innovation is a significant driver behind CPLM and can be delineated into (1) product innovation and (2) workflow innovation (Grieves, 2006; Schindler, 2010). Product innovation is an improvement to a characteristic of a product that in turn adds value by reducing the time and materials required to complete the task (Schindler, 2010). An example of product innovation is demonstrated by Boeing in the creation of vent ducts for F/A-18 E/F/G Super Hornet jet fighters used by the Navy and Marine Corps. Because of the product innovation process, replacement parts are lighter and stronger than those created in traditionally formative processes and can be produced as needed by the customer versus stockpiling spares within a warehouse (Zelinski, 2012). CPLM does not develop new ideas but frees resources (in this case, engineers and designers) to focus on innovation because engineers have an increased visibility of what the customer needs and can provide value-added solutions without expending additional resources (Schindler, 2010).

Workflow innovation focuses on finding improved methods and technologies in order to reduce the amount of time, energy, and resources needed to produce a product or provide a service (Schindler, 2010). Engineers at the Naval Surface Warfare Center (NSWC) Port Hueneme developed a new approach for the measurement and alignment of the SPY-1 radar output onboard the Navy's Ticonderoga-class cruisers and Arleigh Burke–class destroyers by using products created by AM machines. The original process took the ships out of operational employment for six days: two days to erect and take down the scaffolding, and four days to conduct the testing. The new process removes the need for scaffolding, reduces the overall manpower needed (not counting manpower needed to erect the scaffolding) from

three to two, and provides a measurement more accurate than the original method (Poland, 2008, p. 6). The Navy calculated that this innovation will provide an overall savings in excess of $1.6 million over a four-year period (Poland, 2008).

4. Promote Collaboration

Collaboration is when two or more individuals or organizations work together to pursue a common goal (Schindler, 2010). Figure 9 gives a representational picture of CPLM brought into the engineering process (http://www.productlifecyclemanagement.com).

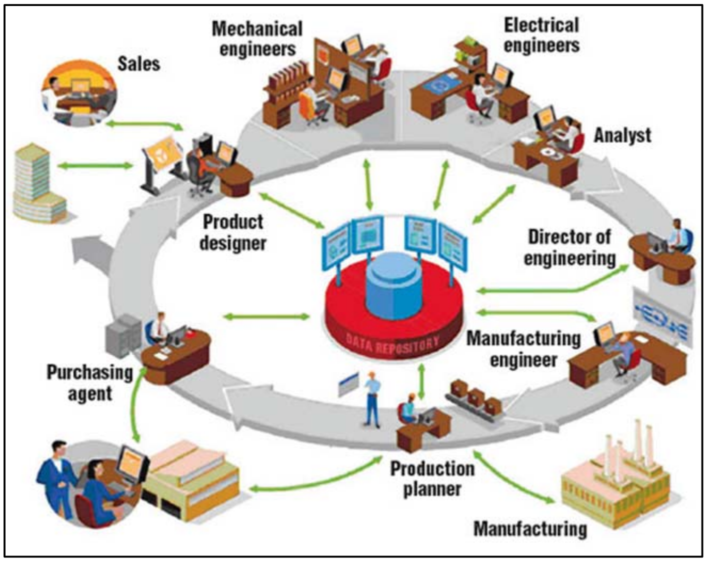

Figure 9. Notional Representation of Product Lifecycle Management
(Product Lifecycle Management, n.d.)

5. Improve Quality

Schindler (2010) stated that "a product that lacks quality will at best result in wasted time, material, and require energy to repair it, and at worst, it could cause injury or death" (p. 26). CPLM provides a consistent, singular view of the represented product's digital data, which removes ambiguity and builds consensus among its users. By having this type of support in the design of a product, CPLM enables improved communication and understanding that will lead to overall improvement in the product's output (Schindler, 2010).

F. SUMMARY

The purpose of this chapter was to initiate discussion about what AM is and what it can bring into the Navy maintenance program. First, it was necessary to show that the traditional acquisition of spare parts needed for the repair of operational units can be hindered by lag times that only serve to decrease overall operational capability. Then, the Navy's maintenance levels needed to be explained in order to show, in their hierarchy, how the Navy expects maintenance to be performed at a particular maintenance level and by whom. Displaying the maintenance levels further demonstrated the level of complexity of the repair capability associated with the level of skill and scope correlated with a particular maintenance level. Describing the differing maintenance levels is important because, based on the maintenance-level capability, the ability to generate spare parts that are not readily available via supply resources and are time critical to repair operational units may have to be assigned to a particular maintenance level. The maintenance level's ability to handle the complexity of the repair part needed to be produced relies on personnel skill levels, available machinery and tooling, and on-demand knowledge resources.

Next, it is important to discuss the technical analysis of AM to show what its capabilities are as of 2013 in order to provide an improved understanding of where the technology stands in its life cycle, and to show where in the TLC AM is in order to show its potential. Next is a discussion of the process of performing part generation using AM. This description demonstrates the necessary steps of using AM, their input requirements, and the expected outputs in order to help the reader better understand the assumptions created to support the KVA and process analysis models in follow-on chapters. From there, the process of how part generation is performed using AM is discussed to demonstrate how the necessary steps, their input requirements, and the expected outputs can be comprehended in order to further the reader to a level of better understanding about the assumptions created to support the KVA and process analysis models in follow-on chapters. Finally, this chapter looks at the inclusion of CPLM software into maintenance activities to further improve communication between stakeholders and the added benefit that CPLM software brings.

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III. METHODOLOGY

A. PURPOSE

The purpose of this chapter is to introduce the methodology that was used to complete the findings of the main study presented in Chapter IV. The KVA processes developed by Housel and Bell (2001) and the completed research conducted by Komoroski (2005) and Seaman (2006) were the mainstays in the construction of this methodology. From here, the use of KVA and process modeling of a notional Navy D-Level maintenance activity shows whether the introduction of CPLM tools and AM provide any viable change in the output of making repair parts.

B. KNOWLEDGE VALUE ADDED

It is first important to understand the concept of value. With the introduction of a new IT product into a process within an organization, value may take the form of improved competitiveness, the expansion of markets, increased capabilities, and an improvement in overall, measurable efficiency (Komoroski, 2005). From here, the particular value that an organization or activity gains from the introduction of a new IT product, be it CPLM software and/or AM machinery, relies on the already existing culture of the organization, its management, and its commitment to maintenance and training of its employees (Komoroski, 2005). When determining value, it is often described using financial terms and metrics. Most often, these metrics are represented by each cost per unit input to the total process output, or outputs over inputs. The issue is that these financial methods often fail to capture the overall benefits produced by individual processes and resources in common, comparable units that can be measured against one another (Komoroski, 2005). When analyzing the working of government activities, like D-Level outputs where there is no profit generation, measuring the outputs in comparison to for-profit private-sector companies needs to have an alternative common unit of measurement in order to determine its value. KVA provides that common unit of measurement for value. KVA output is the end result of an organization's process, as shown in Figure 10.

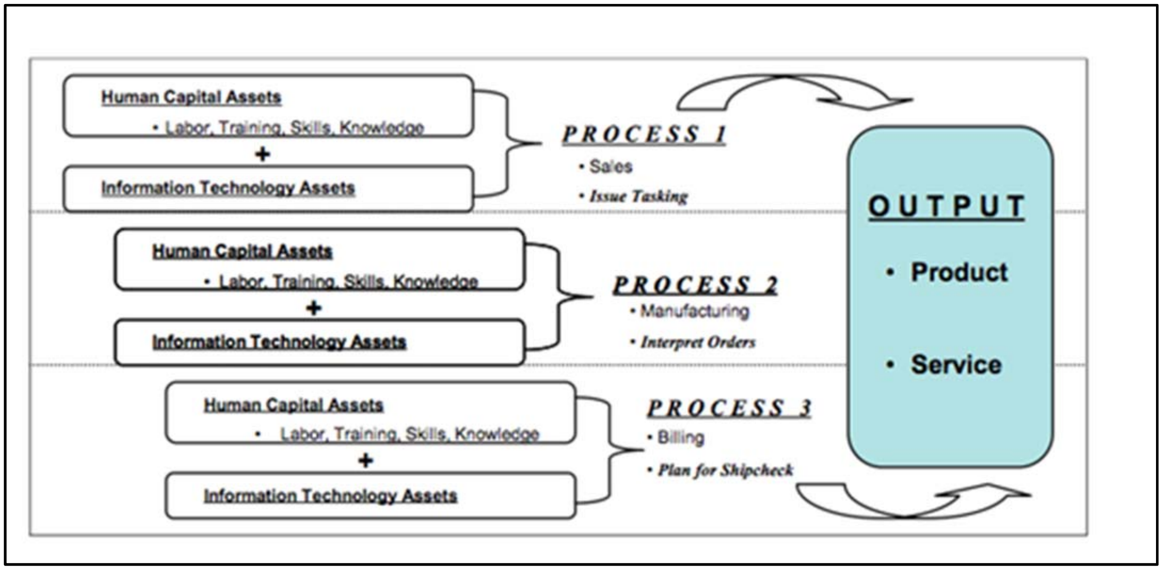

Figure 10. Knowledge Value Added Process in Measuring Output
(Housel & Bell, 2001)

The KVA methodology is a framework that provides analytical analysis of an organization's or activity's knowledge assets. Knowledge assets are those entities within an organization that, through the application of knowledge, provide enhanced products, services, and features that ultimately create value (Housel & Bell, 2001). These assets can be employees, IT products, organizational capabilities, or specific processes or subprocesses. Applying KVA allows the ability to measure these knowledge assets from where they reside within the organization, whether that is a core process, IT products, or an individual or group of employees. When KVA is used to determine the amount of existing knowledge that knowledge assets provide within a core process, no matter where they are located, a ratio known as ROK is generated (Housel & Bell, 2001). When market-comparable metrics are available and revenue comparisons are needed, KVA can provide an ROI output (Komoroski, 2005). Table 6 breaks down the metrics of ROK and ROI.

Table 6. Knowledge Value Added Metrics (Housel & Bell, 2001)

Metric	Description	Type	Calculation
Return-on-Knowledge (ROK)[2]	Basic productivity, cash-flow ratio	Sub-corporate, process-level performance ratio	Outputs-benefits in common units/cost to produce the output
Return on Investment (ROI)	Same as ROI at the sub-corporate, process level	Traditional investment finance ratio	(Revenue-investment cost)/investment cost

KVA holds its theory based on the basic principles of thermodynamics with specific emphasis on the concept of entropy, meaning a change in the environment or in output (Housel & Bell, 2001). Housel and Bell (2001) described the outputs of an organization as units of complexity. They stated that as an organization collects input from sources, value is added to it, thereby changing it to an output; the amount of value added due to this change is directly proportionate to the overall amount of necessary transformation of the input (Komoroski, 2005). From evaluating its value, it can be deduced that a unit of change is a unit of complexity giving a common unit in which to measure an organization's outputs. By thoughtful estimation of this value, KVA creates an analytical tool to determine ROK and/or ROI, thereby creating a common unit of measurement.

When the knowledge of core processes within an organization is measured and placed into numerical format, decision- and policy-makers are better able to determine where inside of their organization they can reengineer a process in order to maximize value. The most prevalent benefit of this information stems from better decisions and policies because management can see what returns a particular process generates. When common units of knowledge are observed within an organization's core processes and measured in terms of cost, management can redirect its investment focus to value creation versus cost containment (Komoroski, 2005).

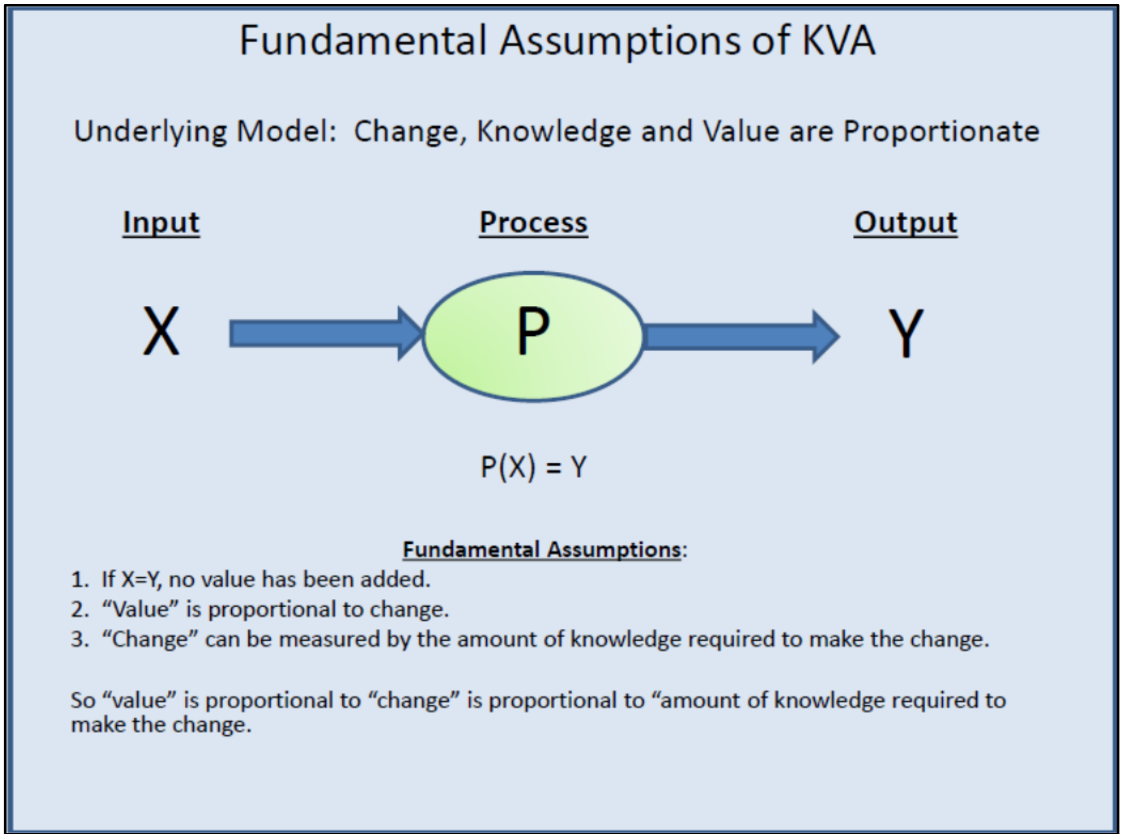

Figure 11. Assumptions of Knowledge Value Added
(Housel & Bell, 2001)

The fundamental assumptions of KVA (as presented in Figure 11) represent the foundation of the KVA process. Accepting the fundamental assumptions of KVA allows the methodology to break all input down into one common unit of output, thereby allowing an organization's processes to become a baseline reference (Komoroski, 2005).

C. IDENTIFYING AN ORGANIZATION'S CORE PROCESSES

In order to calculate the amount of knowledge present within each of the processes into a manner in which KVA can be applied, one must have a firm understanding of an organization's core processes. By having a good understanding and comprehension of what each process entails, the amount of change that a particular element of the process produces can be defined. In the case of this research, a business workflow model exists to describe the core processes of a D-Level maintenance facility. When the processes and subprocesses are identified, boundaries must be established in order to determine the end output of that

process (Housel & Bell, 2001). If an IT product contributes to a particular process, it must be isolated in order to measure the effect it has on that particular process (Komoroski, 2005).

D. APPROACHES TO KNOWLEDGE VALUE ADDED

The knowledge residing within a core process can be shown as learning time and process description approaches, with a binary query method omitted from this research. Theoretically, if either the learning-time approach or the process description approach adequately covers the basic KVA assumptions, then the results will be the same as long as the approach captures the "know-how" of the process outputs, given its particular inputs (Komoroski, 2005). Table 7 shows the three approaches to KVA and displays their applicable steps.

Table 7. Three Approaches to Knowledge Value Added (Housel & Bell, 2001)

Steps	Learning Time	Process Description	Binary Query Method
One	Identify core process and its subprocesses.		
Two	Establish common units and level of complexity to measure learning time.	Describe the products in terms of the instructions required to reproduce them and select unit of process description.	Create a set of binary yes or no questions such that all possible outputs are represented as a sequence of yes or no answers.
Three	Calculate learning time to execute each subprocess.	Calculate number of process description words, pages in manual, and lines of computer code pertaining to each subprocess.	Calculate length of sequence of yes or no answers for each subprocess.
Four	Designate sampling time period long enough to capture a representative sample of the core processes final product or service output.		
Five	Multiply the learning time for each subprocess by the number of times the subprocess executes during the sample period.	Multiply the number of process words used to describe each sub process by the number of times the subprocess executes during sample period.	Multiply the length of the yes or no string for each sub process by the number of times the subprocess executes during sample period.
Six	Calculate cost to execute knowledge (learning time and process instructions) to determine process costs.		
Seven	Calculate ROK and ROP and interpret the results.		

1. Learning-Time Approach

Within the learning-time approach, knowledge is embedded within a core process and is represented by the total amount of time required for an average individual to learn how a process works. In order for a person to adequately learn a process, he or she must be able to successfully replicate the process output consistently. Learning time must become proportional to the knowledge learned in order to be measured, thereby displaying how much knowledge is embedded within that particular process (Komoroski, 2005). For the purposes of this research, learning time is annotated as actual learning time (ALT). ALT is measured in units of time and represents common units of output, described using the variable total knowledge. In the setup for this research, it was determined that SMEs in their respective fields would be able to produce supportive estimates of each member of a process in which ALT is required. For each estimate, it is essential that the amount of knowledge be counted only (1) when it is in use (otherwise there will be an inflated estimation for the amount of knowledge for each given process) and (2) if the knowledge present is required to accomplish the process (Komoroski, 2005).

2. Establishing Reliability

In order to maintain reliability for this research, it was important to calculate the correlation between ALT, the ordinal ranking of critical processes, and the relative learn time (RLT) for each process (Komoroski, 2005). A correlation value needs to be determined between the knowledge times in order to determine reliability. If the correlation value is greater than 80%, then the estimated learning time is reliable. If it is less than 80%, then the SME estimation needs to be reassessed. ALT, ordinal ranking, and RLT are described as follows:

ALT is an estimate for the period of time it takes to teach the average person how to execute a specific process the same way every time, given that there is no time limit to learn the process (Komoroski, 2005).

Ordinal rank measures the amount of complexity within a process by describing how difficult it is to learn. The process is ranked in order from the process that is easiest to learn to the process that is hardest to learn (Komoroski, 2005).

RLT is the measurement of the total time required to teach the average person the core processes given only 100 units of time (e.g., hours, days, months, years). The SME allocates the units according to each process with the expectation that more units allocated represents more complex processes.

Using this manner of correlation between ALT, ordinal rank, and RLT is the preferred method in order to obtain a high degree of reliability (Housel & Bell, 2001).

3. Total Learning Time

This research needed to capture the existing amount of knowledge within a process that is provided by IT products and did so by taking into consideration the amount of automation within a process. The amount of IT used, annotated as a percentage, is added to the learning time in order to calculate the total learning time (TLT). According to Komoroski (2005), the "revenue attributed to IT-based knowledge, plus the cost to use the IT, often reveals that the value added to processes by IT applications, as shown in its resulting ROK ratio, is not always equal to the percentage of IT and automation used in the process" (p. 53).

4. Process Instructions Approach

The purpose of the process instructions approach is to increase the reliability of estimates and requires SMEs to break down each process into subprocesses and identify the specific instructions of that subprocess in order to provide better estimates of ALT (Komoroski, 2005). Collecting and adding up the ALT of each subprocess thereby enables an improved estimate of the core process's ALT.

E. MEASURING KNOWLEDGE AND UTILITY EXECUTIONS

The total number of times that a knowledge asset provides value, and the total amount of time that it takes to execute that process (cost), needs to be accounted for and provide the inputs for the ROK value (Komoroski, 2005). From there, the total time that it takes to do a process is multiplied by the cost and provides a flow-based estimate of the total cost.

1. Return on Knowledge

ROK is a ratio in which the numerator represents the percentage of revenue allocated to the amount of knowledge required to complete a given process successfully and in

proportion to the total amount of knowledge required, thereby generating the total outputs of that process (Komoroski, 2005). ROK's denominator shows the cost of knowledge execution. If ROK is high, then the knowledge asset is better utilized; conversely, if the ROK is low, then the knowledge asset is not being utilized enough. KVA enables the measurement of how each process is performing by converting knowledge into a value, thereby giving decision-makers the ability to gauge how well an investment into training is paying off (Komoroski, 2005). This analytical display can help determine how knowledge can be more effectively employed in order to produce better returns. In the case of IT not increasing ROK, it can be assessed that the investment in IT has not met its worth.

F. SUMMARY

The purpose of this chapter was to describe the methodology involved in determining whether the inclusion of AM and CPLM software into a notional Navy maintenance level will increase benefits. If an added benefit is present, it can be determined that costs related to doing business within a level of maintenance will be decreased. Utilizing the KVA methodology provides an avenue in which creation of the ratios ROK and ROI shows whether this inclusion of IT into the maintenance process reduces overall costs.

IV. METHODOLOGY PROOF OF CONCEPT

A. INTRODUCTION

The Navy's active component for maintenance activities includes 12 shore-based aviation intermediate maintenance departments (AIMDs) located within six fleet readiness centers (FRCs); six shore-based overseas AIMDs; 21 shipboard AIMDs (e.g., aircraft carriers, large-deck amphibious ships); and eight ship/submarine intermediate maintenance activities (IMAs) located at shore facilities and afloat tenders (DoD, 2011). The proof of concept for this research was generated from data collected from the FRC in Naval Air Station North Island, San Diego, California, which is one of six aviation D-Level facilities. The ability of an FRC to manufacture parts extends to a significant number of platforms, such as F/A-18, E-2, C-2, MH/SH-60 (variants), and LM2500 marine gas turbine engines that are utilized onboard most Navy surface combatants. The other aviation maintenance depots are geographically dispersed throughout the world in order to support fleet operations.

The following proof-of-concept analysis takes inputs from SMEs and creates an as-is business process model of the outputs (repair parts) generated from the manufacturing program of a D-Level maintenance activity. Utilizing the KVA methodology that is focused on the manufacturing program, reengineered processes are implemented into the maintenance activity in order to see whether there is a positive or negative impact on the notional process. Two IT assets—AM machines (3D printers) and CPLM software—are brought into two notional, incremental scenarios in order to see the potential impacts. Introducing AM and CPLM is assessed and analyzed in a first incremental to-be (AM only) model and a second incremental to-be (AM + CPLM) model, respectively. Finally, a radical to-be model is displayed to demonstrate AM's potential to produce final repair parts. If, after the IT assets are introduced, ROK increases and other cost estimates improve, then value was added into the process, and vice versa if a decrease in ROK occurs.

The information used in the creation of the KVA models was generated through data collected from SMEs who have extensive experience working within Navy D-Level maintenance activities. This information was then generalized in order to better understand the entire process that would normally be undertaken by these organizations throughout the

Navy. It has to be understood that this data is not perfect but can be deemed reliable based on the high levels of correlation shown within the KVA rankings. Also, this research did not take into account the costs associated with the implementation of CPLM software, the purchase of AM machines as a capital investment, or the cost of the material involved. This type of overhead cost analysis was not performed due to time constraints associated with the scope of the KVA research and analysis. The area of research involved with the introduction of this technology as a means of providing cost reduction and improvement to the operational readiness of the Navy provides multiple sub layers that can be modeled to increase the overall accuracy.

B. NOTIONAL DEPOT-LEVEL PROCESS

The total aggregate data was obtained through interviews with SMEs involved with D-Level maintenance repair part manufacturing within the Navy. Each SME has more than 15 years' experience in manufacturing technology in either military or commercial industries. SMEs explained seven core processes needed to create repair parts at the D-Level, as shown in Figure 12. The notional part that is to be created, called Widget A, is a highly complex part that, according to interviews with SMEs, would be around $6,000 per unit if purchased from the commercial market. More explanation regarding the specifics of each actor's cost, actual learning time, and assumptions are outlined in Section C of this chapter.

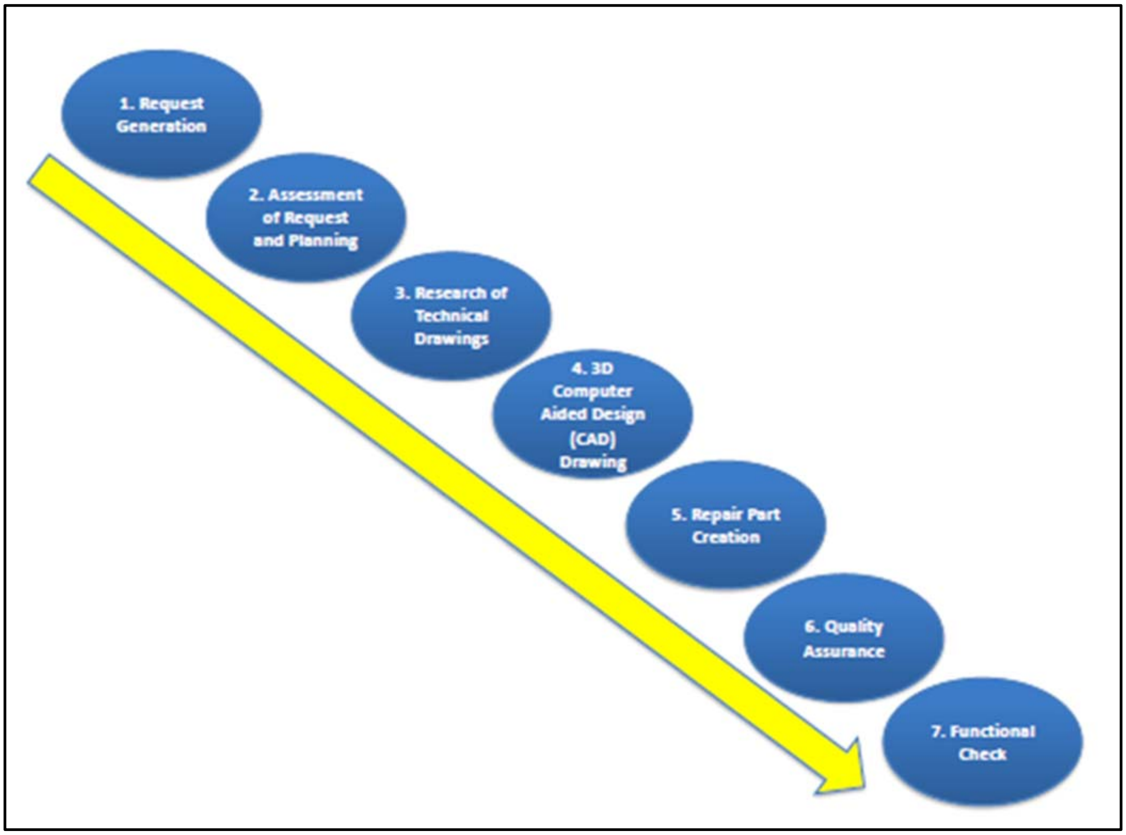

Figure 12. Repair Part Manufacturing Process

This notional process is performed each time a repair part is created at a manufacturing shop. The following is a description of each of the core processes within repair part manufacturing. It is assumed that this notional core process is, in most ways, in effect at each D-Level maintenance activity that manufactures repair parts.

1. Request Generation

The DLA receives a request from the operational unit. This request can go to any DLA decision-maker, who then takes an average of two (2) hours (+/- five minutes) to evaluate and decide how the part is going to be acquired. If the part is within the stock system, the DLA issues the part to the squadron. If not, it is assumed that the original equipment manufacturer (OEM) cannot make the part, resulting in the DLA sending a request to an FRC.

2. Assessment of Request and Planning

FRC management receives the order from the DLA; convenes a meeting with tech librarians, engineers, machinists, quality assurance (QA) inspectors, and mechanics to assess the feasibility of creating the repair part; and, if part creation is feasible, generates assignments and duties in order to create the part. This meeting can last for two (2) hours (+/- 15 minutes), and it is assumed for the purposes of this model that meeting attendees are only talking about Widget A and not assessing any other repair parts. Following this meeting, the FRC management sends a response to the DLA and, if the part can be created, begins the in-house process.

3. Research of Technical Drawings

The tech librarian reviews the applicable repository for any tech drawings applicable to Widget A. If none are found, the tech librarian contacts the OEM and other D-Level activities to find out whether the tech drawing is out there. If a 3D CNC tech drawing is found, the tech librarian delivers it to the machinist for production. At this point, the assumption is that the engineer does not have to make any changes or modifications to the tech drawing. If no tech drawing is found, then the tech librarian confers this information to the engineer. This process takes four (4) hours (+/- 30 minutes).

4. 3D Computer-Aided Design Drawing Creation

The engineer, when notified that the tech drawing is not CNC ready, makes a decision on how to generate the file for the machinist. From here, the engineers have the option of either creating the tech drawing utilizing CAD (16 hours, +/- one hour) or, if the physical part is available, performing a 3D scanning process and generating a CAD file (eight hours, +/- 15 minutes). For this physical part, it is assumed that an example of Widget A was provided by a source for the use of modeling. Upon completion of a CAD file, the engineer delivers it to the machinist. Further down the process, there are two (2) instances that could trigger the "rework" activity. The first is if Widget A fails a QA inspection, and the second is if it fails the functional check activity. If rework occurs, the process takes two (2) hours (+/- 60 minutes), and it is assumed that the engineer is performing adjustments to the CAD based on the input that the QA inspectors or mechanics provided.

5. Repair Part Creation

The machinist, upon receipt of the CAD file, uploads it into the respective CNC machine and begins the subtractive manufacturing process utilizing stock pieces of aluminum block. Assumptions here are that the machinist understands the CAD file and does not have questions for the engineer. This process takes 12 hours (+/- 30 minutes) and results in a finished product, which is delivered to QA for inspection.

6. Quality Assurance

QA takes Widget A and conducts the inspection in accordance with Federal Aviation Administration (FAA) standards on a computer measuring machine. The process takes 10 hours (+/- 60 minutes), which results in either the part passing or failing. If the part fails, it is sent back to the engineers for rework and proceeds through the process cycle again. If the part passes, it is sent to the mechanics.

7. Functional Check of Repair Part

Upon receipt of Widget A, a group of three (3) mechanics performs a functional check by installing the repair part into an F/A-18, located on site, specifically used for this purpose. The process takes 12 hours (+/- 60 minutes) and results in either passing or failing the functional check. If the functional check activity results in a failure, the repair part is sent back to the engineers with adequate descriptions for the rework process. If the part passes, the process ends with the completed part delivered to the squadron.

C. KNOWLEDGE VALUE ADDED ANALYSIS OF AS-IS SCENARIO

Appendix B contains the overall KVA summary generated by Process Modeler[1] from data gathered by interviews with SMEs at an FRC and at NAVSEA. This analysis is a sample of the generation of repair parts within a typical manufacturing shop found at D- and I-Level maintenance activities throughout the Navy. All estimates provided are conservative and as accurate as possible.

[1] Process Modeler is a trademark of Savvion Business Models licensed to Naval Postgraduate School.

1. Employees

The number of employees involved with the building of this reengineering model was the number of personnel needed to manufacture one repair part and did not include the total number of personnel who belong to the FRC machining shop. From the number of personnel utilized within the process, the total amount of knowledge available was calculated and provided.

2. Time Calculation to Create a Repair Part

From interviews with SMEs at an FRC, it was estimated that around 27,000 repair parts for aircraft are produced each year by about 400 employees. The range of these parts extend from very simple, low-complexity parts that are generated quickly to highly complex parts that require significantly more time to produce. It is this type of complex part that was used to support the modeling within this research due to the assumption that modeling the most complex parts that can be generated supports a more conservative approach for estimation. In all, an FRC produces about 5,000 of these highly complex parts each year, approximately 19% of the total output per year. Given this estimate and using the modeling software, it takes approximate 39 man-hours to complete a single repair part.

3. Actors and Actual Learning Time

This section describes the roles of each actor and the assumptions made about the educational background required to perform each particular function within the manufacturing process. The information about the actors was provided through interviews with SMEs, and the assumptions were generated based on those interviews.

The as-is process model involves seven (7) actors: DLA decision-makers, management, tech librarians, engineers, machinists, QA, and mechanics. For the purposes of this research, all actors, with the exception of DLA decision-makers, belong to the FRC organization and reside within one shop/building. The workers identified here work an eight-hour day in a shop that operates only one eight-hour shift, 230 work days a year.

Assumptions about the actors' roles and hourly rates were generated from interviews with FRC SMEs. Hourly rates were derived from U.S. government general schedule (GS) and wage grade (WG) pay scales and determined based on the average employee within that

particular function. Locality and special pays were not factored in, all hourly rates are based on hourly basic rates (B) by grade and step, and no overtime rates are included. Private-sector wage comparisons, when calculated, are measured at 50% more per hour (1.5 x calculation). The following are the actors' assumptions:

A. DLA decision maker—determines that the repair part generation is too cost prohibitive to utilize OEM and makes the decision to utilize FRC resources to generate the part. This person has a minimum of a bachelor's degree and three years' experience in the position. He or she is a GS-11, Step 5, and earns an hourly rate of $27.31 per hour.

B. FRC management—receives the request from the DLA, then confers with all members involved in the repair part generation to calculate feasibility. This person issues assignments and assigns personnel involved with the repair part generation. He or she is a GS-12, Step 5, and earns an hourly rate of $32.73.

C. Tech librarian—responsible for maintaining the part technical diagrams (tech drawings) library and researching in-house databases. This person possesses on-the-job training (OJT), is a GS-6, Step 5, and earns an hourly rate of $16.60.

D. Engineer—responsible for the creation of tech drawings utilizing blueprints, two-dimensional (2D) CADs, or 3D CADs. This person holds a degree in engineering with five years' experience. He or she uses his or her own choice of CAD software and is highly proficient. This person is a GS-11, Step 5, and earns an hourly rate of $27.31.

E. Machinist—responsible for creating the repair part utilizing available manufacturing machinery located within the shop. This person has been trained through technical schooling and holds certificates of training for the machines utilized from the manufacturer. He or she is a WG-9, Step 5, and earns an hourly rate of $25.70.

F. QA inspector—responsible for inspection of created repair parts generated by the machinist against industry and government standards. In the case of the F/A-18, those standards include all applicable FAA regulations. This person is certified by FAA and Naval Air Systems Command (NAVAIR) to perform QA on DoN aircraft. He or she has an average of six years' experience, is a GS-9, Step 5, and earns an hourly rate of $22.57.

G. Mechanic—responsible for the installation and testing of repair parts utilizing an F/A-18 test bed. This person's training was completed by a technical school and is certified and qualified by Commander Naval Air Forces Instruction (COMNAVAIRFORINST) 4790 (series) to perform maintenance

by NAVAIR on its aircraft. He or she has an average of 10 years' experience, is a WG-8, Step 5, and earns an hourly rate of $24.25.

ALT is the amount of time required in order for a worker to perform a particular function. For example, in the case of the QA inspector, in addition to the training required to become certified as a QA inspector, this individual has to undergo specific training on computer measuring machines in order to operate them, comprehend and interpret results, and generate reports. This training time takes 100 hours of additional training, so 100 hours are used for ALT with regard to QA inspectors. In addition, the assumption is that the knowledge utilized per function is counted only if it is actually used to produce a unit of output.

4. Determining Value

Each function within the process of making a repair part involves a percentage amount of IT, ranging from 0% to 100%. This percentage (%IT) represents the amount of knowledge embedded within that function due to the IT supporting it. Measuring the amount of embedded IT is important to account for the IT resources involved in the process and to make consistent, conservative estimates. Utilizing the %IT is required to calculate the TLT. When calculating TLT for instances of low-percentage IT enablers (<60%), ALT is added into the multiplied output of ALT x %IT. High %IT is considered to be any function that has greater than 60% IT and utilizes ALT+(ALT/(1-%IT)) in order to calculate TLT.

5. As-Is Process Analysis

a. Key Assumptions

As mentioned earlier, the data gathered for this research was based on interviews with SMEs, related research, and current information about Navy maintenance activities. From this, the following assumptions were made and modeled:

- Even with 400 personnel assigned to the machine shop, only 13 personnel are involved with the generation of a repair part. The cost is calculated using 13 actors.
- The market-comparable labor contractor rate is 50% greater than the current government labor rate.
- The price per common unit of output is $0.05.

- The cost of the materials to produce the parts, the cost of machinery and IT assets, and infrastructure cost (e.g., electrical) are not included.

b. Knowledge Value Added Analysis

Table 8 shows the key as-is KVA estimates that were utilized in order to determine process benefits, ROK, and ROI.

Table 8. As-Is Knowledge Value Added

AS IS														
Processes	Actual Learning Time	Nominal Learning Time	Times Fired (Cycle Time)	#PEOPLE	% IT	Total Learning Time	Total Output per hour	Total Input per Hour	Cost per hour	Numerator (Benefit)	Denominator (Cost)	Total Knowledge	ROK	Cost to Benefit Ratio
Determine Request	40	7	0.0163563	1	20%	48	0.7851032	0.0330901	$141.29	$3.88	$4.68	37.68495219	82.93%	-17.07%
Performs Function Check	80	10	0.0100654	3	10%	88	2.6572723	0.3637393	$72.75	$13.12	$26.46	701.5198792	49.59%	-50.41%
Receive Request	16	3	0.0251636	1	10%	17.6	0.4428787	0.0519628	$26.50	$2.19	$1.38	7.794665325	158.83%	58.83%
Sends Rqst to Depot	2	1	0.0163563	1	20%	2.4	0.0392552	0.0330901	$26.50	$0.19	$0.88	0.09421238	22.11%	-77.89%
Convert CAD Drawing	80	9	0.0025164	1	20%	96	0.2415702	0.0182436	$27.31	$1.19	$0.50	23.19073981	239.43%	139.43%
Determines how to design Part	80	8	0.0100654	1	20%	96	0.9662808	0.020005	$27.31	$4.77	$0.55	92.76295924	873.41%	773.41%
Reverse Engineer	160	16	0.0075491	1	50%	240	1.8117765	0.1235531	$27.31	$8.95	$3.37	434.8263714	265.16%	165.16%
Rework of Part Design	2	8	0.0515853	1	20%	2.4	0.1238047	0.1004026	$27.31	$0.61	$2.74	0.297131354	22.30%	-77.70%
Send CAD to Machinist	1	1	0.0100654	1	10%	1.1	0.011072	0.0025164	$27.31	$0.05	$0.07	0.012179165	79.56%	-20.44%
Library Check	16	2	0.0150981	1	20%	19.2	0.2898842	0.0612733	$16.60	$1.43	$1.02	5.565777554	140.74%	40.74%
Interprets CAD	24	7	0.0100654	1	10%	26.4	0.2657272	0.0099396	$25.70	$1.31	$0.26	7.015198792	513.70%	413.70%
Make Part	120	14	0.0666834	1	70%	204	13.603422	0.7973075	$25.70	$67.18	$20.49	2775.098138	327.84%	227.84%
Inspects Part	100	14	0.0666834	1	40%	140	9.3356819	0.6612984	$22.57	$46.10	$14.93	1306.995471	308.88%	208.88%
Totals:	721	100	N/A	15	N/A	981.1	30.573729	2.2764217	$494.16	$150.98	$77.31	5392.857675	195.29%	95.29%

From modeling and analysis, the as-is produced, on average, one repair part every 39.4 man-hours. Correlation of the data measured at 90.4%, well above the 80% needed for data validation. Within the as-is process, the importance of engineers, machinists, and mechanics performing their functions provided significant input towards ROK and ROI. It was observed through the modeling that the need to perform rework greatly impacted the amount of repair part generation output due to particular time-intensive steps having to be performed again, at a cost of man-hours. The reduction of the cost due to rework was the focus of the first increment of the to-be model.

6. First Increment To-Be Knowledge Value Added Analysis

a. Key Assumptions

The purpose of the first increment, as mentioned earlier, was to reduce cost associated with rework within the manufacturing of repair parts. AM machinery was introduced into the process, and, using the modeling software, the following assumptions were applied:

- Through the development of a prototype part, communication will improve between engineers, machinists, mechanics, and QA actors.
- Engineers are responsible for printing out the prototypes from the AM machines.

- The conceptual output provided by AM machines will reduce the amount of time for each following actor to complete their portion of the process. For example, machinists will be able to better orient the CAD model on CNC machines, reducing support structures and finishing times.
- Feedback for the design that is provided to the engineers will be beneficial to the end-result product. For example, mechanics will be able to fit test the prototype to ensure that the part to be generated does not have to be modified after creation.
- The cost of the materials to produce the parts, the cost of machinery and IT assets, and infrastructure cost (e.g., electrical) are not included.
- AM machines can only produce prototypes of repair parts; they cannot produce actual repair parts.

b. First Increment Knowledge Value Added Analysis

Table 9 shows the results from the modeling and analysis of the first to-be increment.

Table 9. First Incremental To-Be Model With Additive Manufacturing Knowledge Value Added Estimates

TO BE- with AM														
Processes	Actual Learning Time	Nominal Learning Time	Times Fired (Cycle Time)	#PEOPLE	% IT	Total Learning Time	Total Output per hour	Total Input per Hour	Cost per hour	Numerator (Benefit)	Denominator (Cost)	Total Knowledge	ROK	Cost to Benefit Ratio
Determine Request	40	7	0.0285275	1	20%	48	1.3693219	0.0594689	$141.29	$9.43	$8.40	65.72745227	112.23%	12.23%
Function Check	80	10	0.0102407	3	10%	88	2.703533	0.3759052	$72.75	$18.62	$27.35	713.7327189	68.08%	-31.92%
Mechanic Fit Check	20	0	0.0080462	3	10%	22	0.5310511	0.0278692	$72.75	$3.66	$2.03	35.04937459	180.39%	80.39%
Receive Request	16	2	0.0438885	1	10%	17.6	0.772438	0.0932631	$26.50	$5.32	$2.47	13.59490893	215.24%	115.24%
Sends Rqst to Depot	8	1	0.0285275	1	20%	9.6	0.2738644	0.0614439	$26.50	$1.89	$1.63	2.629098091	115.83%	15.83%
AM Print Out	40	8	0.0241387	1	90%	76	1.8345403	0.3195084	$27.31	$12.63	$8.73	139.4250603	144.79%	44.79%
Adjust Design	20	0	0.0065833	1	20%	24	0.1579987	0.0068027	$27.31	$1.09	$0.19	3.7919684	585.70%	485.70%
Convert CAD Drawing	**80**	9	0.0043889	1	20%	96	0.4213298	0.0379636	$27.31	$2.90	$1.04	40.44766294	279.87%	179.87%
Determines how to design Part	80	8	0.0175554	1	20%	96	1.6853193	0.0375247	$27.31	$11.61	$1.02	161.7906517	1132.57%	1032.57%
Reverse Engineer	160	16	0.0131666	1	50%	240	3.1599737	0.2203204	$27.31	$21.76	$6.02	758.3936801	361.68%	261.68%
Rework of Part Design	8	6	0.0087777	1	20%	9.6	0.084266	0.0175554	$27.31	$0.58	$0.48	0.808953259	121.04%	21.04%
Send to Machinist	2	0	0.0175554	1	10%	2.2	0.0386219	0.0048277	$27.31	$0.27	$0.13	0.084968181	201.74%	101.74%
Library Check	16	3	0.0263331	1	20%	19.2	0.5055958	0.1099408	$16.60	$3.48	$1.83	9.707439105	190.79%	90.79%
Interprets CAD	24	2	0.0175554	1	10%	26.4	0.4634628	0.0199693	$25.70	$3.19	$0.51	12.23541804	621.93%	521.93%
Machinist Plan	20	0	0.0241387	1	10%	22	0.5310511	0.0278692	$25.70	$3.66	$0.72	11.68312486	510.62%	410.62%
Make Part	120	14	0.0351108	1	70%	520	18.257626	0.4355936	$25.70	$125.74	$11.19	9493.965328	1123.19%	1023.19%
Inspects Part	100	14	0.0351108	1	40%	140	4.9155146	0.365372	$22.57	$33.85	$8.25	688.172043	410.51%	310.51%
QA Inspector Plans	20	0	0.0241387	1	10%	22	0.5310511	0.0278692	$22.57	$3.66	$0.63	11.68312486	581.44%	481.44%
Totals:	854	100	N/A	22	N/A	1478.6	38.236559	2.2490674	$669.80	$263.33	$81.97	12162.92298	321.24%	221.24%

The data provided for the to-be output met the correlation requirement by achieving 90.7%. Analysis showed that implementing AM technology into the process produced ROK and ROI at 321.24% and 221.24%, respectively. The amount of rework was reduced by 45%, affecting and thereby reducing the amount of time to produce a repair part from 39.5 man-hours to 22.7 man-hours, a reduction of 57%.

7. Second Increment To-Be Knowledge Value Added Analysis

a. Key Assumptions

The second increment to-be will introduce CPLM software into repair part production in order to see if it will make an impact to the overall process. Assumptions pertaining will introduce the following:

- All D- and I-Level maintenance activities have populated the CPLM repository with 3D CAD technical drawings that they have obtained through OEM resources or by in-house production.
- The 3D CAD technical drawings are valid, meaning that they are uncorrupted files that can be utilized by engineers and machinists.
- Benefits from the first incremental to-be model remain in place.
- The cost of purchasing and implementing CPLM software is already accounted for.
- The cost of the materials to produce the parts, the cost of machinery and IT assets, and infrastructure cost (e.g., electrical) are not included.

b. Second Increment Knowledge Value Added Analysis

Table 10 shows the key KVA estimates that were utilized in order to determine process benefits, ROK, and ROI.

Table 10. Second Incremental To-Be Knowledge Value Added Analysis With Additive Manufacturing and Collaborative Product Lifecycle Management

TO BE- with AM + CPLM														
Processes	Actual Learning Time	Nominal Learning Time	Times Fired (Cycle Time)	#PEOPLE	% IT	Total Learning Time	Total Output per hour	Total Input per Hour	Cost per hour	Numerator (Benefit)	Denominator (Cost)	Total Knowledge	ROK	Cost to Benefit Ratio
Determine Request	40	7	0.0505247	1	20%	48	2.4251846	0.0998834	$141.29	$19.03	$14.11	116.4088613	134.88%	34.88%
Function Check	80	10	0.0181371	3	10%	88	4.788185	0.6478818	$72.75	$37.58	$47.13	1264.080839	79.74%	-20.26%
Mechanic Fit Check	20	0	0.0038865	3	10%	22	0.2565099	0.0112709	$72.75	$2.01	$0.82	16.9296541	245.54%	145.54%
Receive Request	16	2	0.0777303	1	10%	17.6	1.3680529	0.1488535	$26.50	$10.74	$3.94	24.07773028	272.21%	172.21%
Sends Rqst to Depot	8	1	0.0505247	1	20%	9.6	0.4850369	0.0983288	$26.50	$3.81	$2.61	4.65635445	146.10%	46.10%
AM Print Out	40	8	0.0116595	1	90%	440	5.1301982	0.0952196	$27.31	$40.27	$2.60	2257.287213	1548.44%	1448.44%
Adjust Design	20	0	0.0038865	1	20%	24	0.0932763	0.0023319	$27.31	$0.73	$0.06	2.238631947	1149.60%	1049.60%
Convert CAD Drawing	**80**	9	0.0038865	1	20%	96	0.3731053	0.0287602	$27.31	$2.93	$0.79	35.81811115	372.84%	272.84%
Determines how to design Part	80	8	0.007773	1	20%	96	0.7462106	0.0101049	$27.31	$5.86	$0.28	71.63622231	2122.34%	2022.34%
Reverse Engineer	160	16	0.0038865	1	50%	240	0.9327633	0.0571318	$27.31	$7.32	$1.56	223.8631947	469.22%	369.22%
Rework of Part Design	8	6	0.0155461	1	20%	9.6	0.1492421	0.025651	$27.31	$1.17	$0.70	1.432724446	167.21%	67.21%
Send to Machinist	2	0	0.007773	1	10%	2.2	0.0171007	0.0007773	$27.31	$0.13	$0.02	0.037621454	632.28%	532.28%
Library Check	16	3	0.0466382	1	20%	19.2	0.8954528	0.1830548	$16.60	$7.03	$3.04	17.19269335	231.29%	131.29%
Interprets CAD	24	2	0.007773	1	10%	26.4	0.2052079	0.0069957	$25.70	$1.61	$0.18	5.417489312	895.85%	795.85%
Machinist Plan	20	0	0.0116595	1	10%	22	0.2565099	0.0112709	$25.70	$2.01	$0.29	5.643218033	695.06%	595.06%
Make Part	120	14	0.0621842	1	70%	520	32.335795	0.720171	$25.70	$253.80	$18.51	16814.61329	1371.27%	1271.27%
Inspects Part	100	14	0.0621842	1	40%	140	8.7057909	0.5958026	$22.57	$68.33	$13.45	1218.810727	508.14%	408.14%
QA Inspector Plans	20	0	0.0116595	1	10%	22	0.2565099	0.0093276	$22.57	$2.01	$0.21	5.643218033	956.33%	856.33%
Totals:	854	100	N/A	22	N/A	1842.6	59.420132	2.7528177	$669.80	$466.38	$110.30	22085.7878	422.84%	322.84%

From the results, the addition of CPLM software complemented the previous incremental change, producing ROK and ROI percentages of 422.84% and 322.84%, respectively. The amount of time it took to create a part was reduced from 22.7 man-hours to 12.8 man-hours on average, a savings of 56%.

8. Radical To-Be Knowledge Value Added Analysis

The purpose of conducting this radical to-be KVA was to model the potential of AM reaching a mature state that allows the generation of complete repair parts. This capacity, coupled with CPLM software, needed to be modeled in order to estimate potential savings to the Navy.

a. Key Assumptions

This model dramatically impacted the actors and processes leading up the final produced part and included the following assumptions:

- AM machines print out ready-to-use parts.
- Machinists will be able to directly retrieve the CAD files from CPLM and will print out the parts from AM machines instead of engineers.
- Tech librarians are no longer required because the machinists will be able to retrieve the CAD files.
- Previous benefits from first and second increments remain in place.
- The cost of the materials to produce the parts, the cost of machinery and IT assets, and infrastructure cost (e.g., electrical) are not included.

b. Radical Knowledge Value Added Analysis

Table 11 shows the results from the modeling and analysis of the radical to-be increment.

Table 11. Radical To-Be Increment With Additive Manufacturing and Collaborative Product Lifecycle Management

RADICAL TO BE- with AM + CPLM														
Processes	Actual Learning Time	Nominal Learning Time	Times Fired (Cycle Time)	#PEOPLE	% IT	Total Learning Time	Total Output per hour	Total Input per Hour	Cost per hour	Numerator (Benefit)	Denominator (Cost)	Total Knowledge	ROK	Cost to Benefit Ratio
Receive Request	16	7	0.0866927	1	40%	22.4	1.9419159	0.1595145	$26.50	$18.79	$4.23	43.49891634	444.40%	344.40%
Sends Rqst to Depot	8	5	0.0563502	1	70%	34.666667	1.9534749	0.1144343	$26.50	$18.90	$3.03	67.72046429	623.15%	523.15%
AM Print Out	40	15	0.0606849	1	91%	484.44444	29.398449	0.6055483	$25.70	$284.39	$15.56	14241.91537	1827.39%	1727.39%
Adjust Design	20	8	0.0606849	1	60%	32	1.9419159	0.0593845	$25.70	$18.79	$1.53	62.14130906	1230.87%	1130.87%
Function Check	80	15	0.0187834	3	10%	88	4.958821	0.6315561	$72.75	$47.97	$45.95	1309.128739	104.41%	4.41%
Inspects Part	100	40	0.0606849	1	40%	140	8.4958821	0.54443	$22.57	$82.19	$12.29	1189.423494	668.84%	568.84%
CPLM Check	8	5	0.0563502	1	90%	88	4.958821	0.0511487	$32.73	$47.97	$1.67	436.3762462	2865.41%	2765.41%
Request Part File	8	5	0.0043346	1	60%	28	0.1213697	0.0130039	$32.73	$1.17	$0.43	3.398352839	275.85%	175.85%
Totals:	280	100	N/A	10	N/A	917.51111	53.77065	2.1790204	$265.18	$520.16	$84.68	17353.60289	614.25%	514.25%

Radical to-be increment resulted in a significant reduction in the overall time to produce a repair part, decreasing it to 11.2 man-hours per part. ROK and ROI slightly increased to 614.25% and 514.25%, respectively. The radical to-be model provided the most significant reduction to the overall cost of producing a part, at a marginal cost of $619 per part.

V. CONCLUSIONS AND RECOMMENDATIONS

A. RESEARCH LIMITATIONS

Several limitations were present while conducting this research, given the state of AM technology in 2013. As previously mentioned, the analysis of cost to implement AM and CPLM technology was not included due to the time constraints and the lack of available data. In addition, the study of risk analysis from overhead costs relating to implementation, and the application of the real options approach, were not performed. Suggestions for further research into these areas are provided at the end of this chapter.

B. RESEARCH QUESTIONS

From the analysis of this research, the cost savings from the implementation of AM and CPLM technology was determined to be very substantial for the creation of repair parts at Navy D- and I-Level maintenance activities. These technologies provide viable technological capabilities that can improve the capacity and quality of output from these maintenance activities, thereby enabling increased productivity in the direct support to operational units. AM and CPLM, as of 2013, have been implemented in at least one D-Level maintenance activity, demonstrating that the incorporation of these technologies makes it possible for the Navy to use this activity as a model for AM inclusion.

1. Predicted Cost Savings

The result from the introduction of AM and CPLM into the Navy's D-Level maintenance activities indicated substantial cost savings. Extrapolating this model across the entire D- and I-Level maintenance activities indicated potential significant cost savings as a result of implementing AM and CPLM to make repair parts for operational units. Extrapolating D- and I-Level maintenance activities from the Navy's operations and maintenance FY2012 budget (see Appendix B),

- The FY2012 maintenance budget for the Navy's D-Level and I-Level activities was $1.80 billion, distributed among 47 (ship and shore-based) maintenance activities. It is estimated that 30% of the annual budget for the 47 maintenance activities is spent on manufacturing repair parts, which includes labor costs; the result of cost–benefit for the Navy is $642.60 million.

- The cost to implement AM and CPLM manufacturing technology is not included.
- All 47 maintenance activities have the ability to manufacture parts via a machine shop.

Table 12 shows the results from each cost savings model given the addition of the two technologies for all Navy D- and I-Level maintenance activities.

Table 12. Extrapolated Cost Savings for the Navy

	ROK	Cost-Benefit Ratio	Cost Savings per Year
As Is	**195 %**	**51.20%**	**0**
To Be (AM)	**321%**	**221.24%**	**$68.12 million**
To Be (AM+CPLM)	**423%**	**322.84%**	**$178.64 million**
Radical To Be	**614%**	**514.25%**	**$1.47 billion**

By implementing AM and CPLM, the Navy's maintenance activities stand to provide a considerable cost savings from their current operations. The Navy stands to benefit the most from the radical to-be model, which infers that AM technology matures to a level of producing direct replacement-part capability. AM, combined with CPLM, yields the greatest cost/benefit and provides a forecasted $1.47 billion in cost savings.

C. RECOMMENDATIONS TO THE NAVY

Throughout the course of this research, there was a common thread regarding the potential of AM and CPLM technology. Although it is a relatively new technology within the manufacturing industry, AM and CPLM hold the ability to communicate ideas, increase collaboration, and improve efficiency of processes among stakeholders. More importantly, they can improve the manufacturing process, thus increasing the operational readiness of the fleet by providing quality repair parts when needed. AM technology capability is growing and heading to a higher level of capacity. This technology, with the inclusion of CPLM in an organization, should be implemented because it provides the ability to obtain the right

information at the right time because the information is available from within a shared repository. Navy leadership should look into this enabler and monopolize on its ability to share information between entities and provide a viable venue to enable innovation from the personnel within each activity. The greatest impedance to this opportunity are traditional acquisition methods and business relationships with private industry. Traditional acquisition methods inhibit the capabilities of producing repair parts that are available within the Navy's maintenance activities. Existing acquisition policies and directives force the Navy to look outside instead of inside existing lifelines for the generation of repair parts, making operational units highly dependent on these entities. However, it is important that the introduction of these technologies, especially CPLM, be based on strategic policies that support collaboration and guide the management of information.

D. FOLLOW-ON AND FUTURE RESEARCH OPTIONS

The potential of including AM and CPLM to reduce the costs of creating repair parts to maintain operational assets is significant. This research opens up many opportunities for other areas of research to better support decision- and policy-makers within the Navy.

1. Real Options

The use of real options to evaluate the viability of introducing AM and CPLM into the Navy's maintenance activities was not included in this research but should be strongly considered in future research in order to support policy- and decision-makers. The following options present themselves:

- Implement AM technology and CPLM software at all D-Level maintenance activities, and continue their implementation to I-Level if successful.
- Implement AM technology, without CPLM software, at all D-Level maintenance activities, and continue its implementation to I-Level if successful.
- Implement CPLM software between D-Level and systems commands in order to promote the sharing of information. Establish policies for the expectations and use of CPLM software between these entities.
- Continue with the current as-is process.

2. Other Areas of Potential Research

The following questions highlight potential areas of research:

- How can the barriers to adoption of 3D laser scanning technology and CPLM be overcome when these two technologies are combined with AM?
- Utilizing risk-analysis methods, how much risk is involved with the addition of AM and CPLM technology into Navy maintenance activities?
- What are the potential cost savings of implementing AM and CPLM within the Navy's I-Level maintenance activities?
- What is the feasibility of implementing AM and CPLM within the Navy's O-Level maintenance activities?
- What is the cost associated with implementing AM assets throughout the Navy's maintenance activities?
- What system dynamics are affected by the implementation of AM and CPLM into the Navy's maintenance activities?
- What barriers are associated with implementing CPLM software given current policies associated with the Navy/Marine Corps Intranet?
- What are the associated costs and benefits of training active-duty personnel on AM technology?
- What are the potential benefits and cost savings for the Navy in collaborating with discharged personnel who undergo training through non-profit organizations like Workshop for Warriors and are hired on as part of the civilian workforce at Navy maintenance activities?

APPENDIX A. SAVVION MODEL OUTPUTS

AS-IS

Simulation Results

Duration	794:30:00	Time	794.5				
		Time per Part	39.74			6000	Market Price per Unit
						150.9814	revenue per hour

Process Time And Cost

Process	Scenario	Instances	Total Cost	Waiting Time (Time)	Total Time (Time)
DepotMaintenanceProcess	AS IS	20	1723655.21	3504:05:00	5310:30:00
		Cost Per Unit (/20)	$86,182.76		

DepotMaintenanceProcess

Scenario	(default)
Instances	20

Activity	Performer	Occurs	Waiting Time (Time)	Time To Complete (Time)	Total Time (Time)	Worktime	Fired/Hour	AWT
Determine Request	All member(s) of FRC Man	13	2:45:00	26:20:00	29:05:00	26.3	0.01635632	2.023076923
Performs Function Check	All member(s) of Mechanic	24	0:00:00	289:10:00	289:10:00	289.1	0.03019628	12.04583333
Receive Request	Any member of DLA	20	338:50:00	41:20:00	380:10:00	41.3	0.02516356	2.065
Sends Rqst to Depot	Any member of DLA	13	357:30:00	26:20:00	383:50:00	26.3	0.01635632	2.023076923
Convert CAD Drawing	Any member of Engineer	2	39:05:00	14:30:00	53:35:00	14.5	0.00251636	7.25
Determines how to design P	Any member of Engineer	8	108:40:00	15:55:00	124:35:00	15.9	0.01006543	1.9875
Reverse Engineer	Any member of Engineer	6	154:35:00	95:10:00	249:45:00	98.2	0.00754907	16.36666667
Rework of Part Design	Any member of Engineer	41	250:40:00	79:50:00	330:30:00	79.8	0.0515853	1.946341463
Send CAD to Machinist	Any member of Engineer	8	227:05:00	2:00:00	229:05:00	2	0.01006543	0.25
Library Check	Any member of Librarian	12	99:50:00	48:40:00	148:30:00	48.7	0.01509814	4.058333333
Interprets CAD	Any member of Machinists	8	235:50:00	7:55:00	243:45:00	7.9	0.01006543	0.9875
Make Part	Any member of Machinists	53	1688:15:00	633:40:00	2321:55:00	633.7	0.06668344	11.95660377
Inspects Part	Any member of Quality As	53	1:00:00	525:35:00	526:35:00	525.6	0.06668344	9.916981132

Resource	Unit	Cost/Unit	Threshold	Usage	Cost	#People	Utilization
All member(s) of FRC Manag	Hour	149.16	0	26	$3,878.16	1	3.31%
All member(s) of Mechanics	Hour	72.75	0	867	$63,074.25	3	12.12%
Any member of DLA	Hour	26.5	0	67	$1,775.50	1	8.51%
Any member of Engineer	Hour	27.31	0	207	$5,653.17	1	26.47%
Any member of Librarian	Hour	16.6	0	48	$796.80	1	6.13%
Any member of Machinists	Hour	25.7	0	641	$16,473.70	1	80.72%
Any member of Quality Ass	Hour	22.57	0	525	$11,849.25	1	66.13%

Performers Queue Length and Utilization

Name	Average	Min	Max	Utilized(%)	Idle(%)
Any member of Machinists	2.42	0	9	80.72	19.28
Value of 'Creator'	0	0	0	0	100
Generic	0	0	0	0	100
All member(s) of Mechanics	0	0	0	36.38	63.62
Any member of Quality Ass	0	0	1	66.12	33.88
Any member of DLA	0.88	0	18	8.51	91.49
All member(s) of FRC Manag	0	0	1	3.31	96.69
Any member of Librarian	0.13	0	5	6.12	93.88
Any member of Engineer	0.98	0	8	26.1	73.9

Bottlenecks

Process	Activity	Performer	Avg Queue Length	Min Queue Length	Max Queue Length
DepotMaintenanceProcess	Convert CAD Drawing	Any member of Engineer	0.05	0	1
DepotMaintenanceProcess	Determine Request	All member(s) of FRC Ma	0	0	1
DepotMaintenanceProcess	Determines how to design	Any member of Engineer	0.14	0	5
DepotMaintenanceProcess	Inspects Part	Any member of Quality A	0	0	1
DepotMaintenanceProcess	Interprets CAD	Any member of Machinist	0.3	0	5
DepotMaintenanceProcess	Library Check	Any member of Librarian	0.13	0	5
DepotMaintenanceProcess	Make Part	Any member of Machinist	2.12	0	8
DepotMaintenanceProcess	Receive Request	Any member of DLA	0.43	0	18
DepotMaintenanceProcess	Reverse Engineer	Any member of Engineer	0.19	0	4
DepotMaintenanceProcess	Rework of Part Design	Any member of Engineer	0.32	0	4
DepotMaintenanceProcess	Send CAD to Machinist	Any member of Engineer	0.29	0	5
DepotMaintenanceProcess	Sends Rqst to Depot	Any member of DLA	0.45	0	10

Note:	Red-marked Waiting Time values indicates "Activity has waiting time"
	Red-marked Usage values indicates "Usage crossed threshold"

Figure 13. As-Is Model

TOBE_wAM

Simulation Results			
Duration	455:45:00	Time	455.7
			22.785

Process Time And Cost

Process	Scenario	Instances	Total Cost	Waiting Time (Time)	Total Time (Time)
DepotMaintenanceProcess	TOBE_wAM	20	64405.49	2654:35:00	3637:05:00
		Cost Per Unit (/20)	$3,220.42		

DepotMaintenanceProcess

Scenario	TOBE_wAM
Instances	20

Activity	Performer	Occurs	Waiting Time (Time)	Time To Complete (Time)	Total Time (Time)	WorkTime	Fired/Hour	AWT
Determine Request	All member(s) of FRC Man	13	1:30:00	27:05:00	28:35:00	27.1	0.02852754	2.084615
Function Check	All member(s) of Mechani	14	12:15:00	171:20:00	183:35:00	171.3	0.03072197	12.23571
Mechanic Fit Check	All member(s) of Mechani	11	24:05:00	12:40:00	36:45:00	12.7	0.02413869	1.154545
Receive Request	Any member of DLA	20	353:20:00	42:30:00	395:50:00	42.5	0.04388852	2.125
Sends Rqst to Depot	Any member of DLA	13	384:55:00	28:00:00	412:55:00	28	0.02852754	2.153846
AM Print Out	Any member of Engineer	11	542:25:00	145:35:00	688:00:00	145.6	0.02413869	13.23636
Adjust Design	Any member of Engineer	3	62:40:00	3:05:00	65:45:00	3.1	0.00658328	1.033333
Convert CAD Drawing	Any member of Engineer	2	66:15:00	17:20:00	83:35:00	17.3	0.00438885	8.65
Determines how to design P	Any member of Engineer	8	220:50:00	17:05:00	237:55:00	17.1	0.01755541	2.1375
Reverse Engineer	Any member of Engineer	6	283:25:00	100:25:00	383:50:00	100.4	0.01316656	16.73333
Rework of Part Design	Any member of Engineer	4	37:35:00	8:00:00	45:35:00	8	0.0087777	2
Send to Machinist	Any member of Engineer	8	289:45:00	2:10:00	291:55:00	2.2	0.01755541	0.275
Library Check	Any member of Librarian	12	102:30:00	50:05:00	152:35:00	50.1	0.02633311	4.175
Interprets CAD	Any member of Machinists	8	57:55:00	9:05:00	67:00:00	9.1	0.01755541	1.1375
Machinist Plan	Any member of Machinists	11	71:45:00	12:40:00	84:25:00	12.7	0.02413869	1.154545
Make Part	Any member of Machinists	16	114:55:00	198:30:00	313:25:00	198.5	0.03511082	12.40625
Inspects Part	Any member of Quality As	16	3:05:00	166:30:00	169:35:00	166.5	0.03511082	10.40625
QA Inspector Plans	Any member of Quality As	11	25:25:00	12:40:00	38:05:00	12.7	0.02413869	1.154545

Resource	Unit	Cost/Unit	Threshold	Usage	Cost	#People	Utilization
All member(s) of FRC Manag	Hour	141.29	0	27	$3,814.83	1	5.95%
All member(s) of Mechanics	Hour	72.75	0	552	$40,158.00	3	13.46%
Any member of DLA	Hour	26.5	0	70	$1,855.00	1	15.47%
Any member of Engineer	Hour	27.31	0	293	$8,001.83	1	64.45%
Any member of Librarian	Hour	16.6	0	50	$830.00	1	10.99%
Any member of Machinists	Hour	25.7	0	220	$5,654.00	1	48.34%
Any member of Quality Ass	Hour	22.57	0	179	$4,040.03	1	39.32%

Performers Queue Length and Utilization

Name	Average	Min	Max	Utilized(%)	Idle(%)
Any member of Quality Ass	0.06	0	2	39.31	60.69
Any member of DLA	1.62	0	18	15.47	84.53
All member(s) of FRC Manag	0	0	1	5.94	94.06
Any member of Librarian	0.22	0	5	10.99	89.01
Any member of Engineer	3.3	0	8	64.44	35.56
Any member of Machinists	0.54	0	4	48.33	51.67
All member(s) of Mechanics	0.08	0	2	40.37	59.63
Value of 'Creator'	0	0	0	0	100
Generic	0	0	0	0	100

Bottlenecks

Process	Activity	Performer	Avg Queue Length	Min Queue Length	Max Queue Length
DepotMaintenanceProcess	AM Print Out	Any member of Eng	1.19	0	5
DepotMaintenanceProcess	Adjust Design	Any member of Eng	0.14	0	1
DepotMaintenanceProcess	Convert CAD Drawing	Any member of Eng	0.15	0	1
DepotMaintenanceProcess	Determine Request	All member(s) of FR	0	0	1
DepotMaintenanceProcess	Determines how to design	Any member of Eng	0.48	0	5
DepotMaintenanceProcess	Function Check	All member(s) of Me	0.03	0	1
DepotMaintenanceProcess	Inspects Part	Any member of Qua	0.01	0	1
DepotMaintenanceProcess	Interprets CAD	Any member of Mac	0.13	0	3
DepotMaintenanceProcess	Library Check	Any member of Libr	0.22	0	5
DepotMaintenanceProcess	Machinist Plan	Any member of Mac	0.16	0	2
DepotMaintenanceProcess	Make Part	Any member of Mac	0.25	0	2
DepotMaintenanceProcess	Mechanic Fit Check	All member(s) of Me	0.05	0	2
DepotMaintenanceProcess	QA Inspector Plans	Any member of Qua	0.06	0	1
DepotMaintenanceProcess	Receive Request	Any member of DLA	0.78	0	18
DepotMaintenanceProcess	Reverse Engineer	Any member of Eng	0.62	0	4
DepotMaintenanceProcess	Rework of Part Design	Any member of Eng	0.08	0	1
DepotMaintenanceProcess	Send to Machinist	Any member of Eng	0.64	0	4
DepotMaintenanceProcess	Sends Rqst to Depot	Any member of DLA	0.84	0	10

Note:	Red-marked Waiting Time values indicates "Activity has waiting time"
	Red-marked Usage values indicates "Usage crossed threshold"

Figure 14. First Incremental To-Be Model With Additive Manufacturing

TOBE_wAMCPLM

Simulation Results			
Duration	257:20:00	Time	257.3
			12.865

Process Time And Cost

Process	Scenario	Instances	Total Cost	Waiting Time (Time)	Total Time (Time)
DepotMaintenanceProcess	TOBE_wAMCPLM	20	53062.92	1342:40:00	2015:30:00
		Cost Per Unit (/20)	$2,653.15		

DepotMaintenanceProcess

Scenario	TOBE_wAMCPLM
Instances	20

Activity	Performer	Occurs	Waiting Time (Time)	Time To Complete (Time)	Total Time (Time)	Worktime	Fired/Hour	AWT
Determine Request	All member(s) of FRC	13	2:35:00	25:40:00	28:15:00	25.7	0.050524679	1.976923
Function Check	All member(s) of Mech	14	26:10:00	166:40:00	192:50:00	166.7	0.054411193	11.90714
Mechanic Fit Check	All member(s) of Mech	3	25:45:00	2:55:00	28:40:00	2.9	0.011659541	0.966667
Receive Request	Any member of DLA	20	307:10:00	38:20:00	345:30:00	38.3	0.077730276	1.915
Sends Rqst to Depot	Any member of DLA	13	292:40:00	25:15:00	317:55:00	25.3	0.050524679	1.946154
AM Print Out	Any member of Engine	3	2:25:00	24:30:00	26:55:00	24.5	0.011659541	8.166667
Adjust Design	Any member of Engine	1	14:35:00	0:40:00	15:15:00	0.6	0.003886514	0.6
Convert CAD Drawing	Any member of Engine	1	0:00:00	7:25:00	7:25:00	7.4	0.003886514	7.4
Determines how to design P	Any member of Engine	2	0:00:00	2:25:00	2:25:00	2.6	0.007773028	1.3
Reverse Engineer	Any member of Engine	1	0:00:00	14:45:00	14:45:00	14.7	0.003886514	14.7
Rework of Part Design	Any member of Engine	4	0:00:00	6:40:00	6:40:00	6.6	0.015546055	1.65
Send to Machinist	Any member of Engine	2	0:00:00	0:10:00	0:10:00	0.2	0.007773028	0.1
Library Check	Any member of Librari	12	73:55:00	47:10:00	121:05:00	47.1	0.046638166	3.925
Interprets CAD	Any member of Machi	2	1:35:00	1:50:00	3:25:00	1.8	0.007773028	0.9
Machinist Plan	Any member of Machi	3	154:20:00	2:55:00	157:15:00	2.9	0.011659541	0.966667
Make Part	Any member of Machi	16	431:55:00	185:20:00	617:15:00	185.3	0.062184221	11.58125
Inspects Part	Any member of Qualit	16	5:05:00	153:20:00	158:25:00	153.3	0.062184221	9.58125
QA Inspector Plans	Any member of Qualit	3	4:30:00	2:55:00	7:25:00	2.4	0.011659541	0.8

Resource	Unit	Cost/Unit	Threshold	Usage	Cost	#People	Utilization
All member(s) of FRC Manag	Hour	141.29	0	25	$3,532.25	1	9.99%
All member(s) of Mechanics	Hour	72.75	0	508	$36,957.00	3	21.97%
Any member of DLA	Hour	26.5	0	63	$1,669.50	1	24.72%
Any member of Engineer	Hour	27.31	0	56	$1,529.36	1	22.00%
Any member of Librarian	Hour	16.6	0	47	$780.20	1	18.31%
Any member of Machinists	Hour	25.7	0	190	$4,883.00	1	73.84%
Any member of Quality Assu	Hour	22.57	0	156	$3,520.92	1	60.51%

Performers Queue Length and Utilization

Name	Average	Min	Max	Utilized(%)	Idle(%)
Any member of Quality Assu	0.04	0	1	60.72	39.28
Any member of DLA	2.33	0	17	24.71	75.29
All member(s) of FRC Manag	0.01	0	1	9.97	90.03
Value of 'Creator'	0	0	0	0	100
Generic	0	0	0	0	100
Any member of Librarian	0.29	0	4	18.33	81.67
Any member of Engineer	0.07	0	1	21.99	78.01
Any member of Machinists	2.28	0	8	73.87	26.13
All member(s) of Mechanics	0.2	0	3	65.9	34.1

Bottlenecks

Process	Activity	Performer	Avg Queue Length	Min Queue Length	Max Queue Length
DepotMaintenanceProcess	AM Print Out	Any member of Eng	0.01	0	1
DepotMaintenanceProcess	Adjust Design	Any member of Eng	0.06	0	1
DepotMaintenanceProcess	Determine Request	All member(s) of FR	0.01	0	1
DepotMaintenanceProcess	Function Check	All member(s) of Me	0.1	0	1
DepotMaintenanceProcess	Inspects Part	Any member of Qua	0.02	0	1
DepotMaintenanceProcess	Interprets CAD	Any member of Mac	0.01	0	1
DepotMaintenanceProcess	Library Check	Any member of Libr	0.29	0	4
DepotMaintenanceProcess	Machinist Plan	Any member of Mac	0.6	0	2
DepotMaintenanceProcess	Make Part	Any member of Mac	1.68	0	7
DepotMaintenanceProcess	Mechanic Fit Check	All member(s) of Me	0.1	0	2
DepotMaintenanceProcess	QA Inspector Plans	Any member of Qua	0.02	0	1
DepotMaintenanceProcess	Receive Request	Any member of DLA	1.19	0	14
DepotMaintenanceProcess	Sends Rqst to Depot	Any member of DLA	1.14	0	9

Note:	Red-marked Waiting Time values indicates "Activity has waiting time"
	Red-marked Usage values indicates "Usage crossed threshold"

Figure 15. Second Incremental To-Be Model With Additive Manufacturing and Collaborative Product Lifecycle Management

RAD_TOBE_wAMCPLM

Simulation Results

Duration	231:45:00	Time	230.7
		Time	11.535

Process Time And Cost

Process	Scenario	Instances	Total Cost	Waiting Time (Time)	Total Time (Time)
DepotMaintenanceProcess	RAD_ToBe_AMCPLM	20	12389.63	1627:30:00	2127:10:00
		Cost Per Unit (/20)	$619.48		

DepotMaintenanceProcess

Scenario	RAD_ToBe_AMCPLM
Instances	20

Activity	Performer	Occurs	Waiting Time (Time)	Time To Complete (Time)	Total Time (Time)	Work Time	Fired per Hour	AWT
Receive Request	Any member of DLA	20	303:00:00	36:50:00	339:50:00	36.8	0.086693	1.84
Sends Rqst to Depot	Any member of DLA	13	334:00:00	23:25:00	357:25:00	26.4	0.05635	2.030769
AM Print Out	Any member of Machi	14	545:20:00	139:40:00	685:00:00	139.7	0.060685	9.978571
Adjust Design	Any member of Machi	14	312:25:00	13:40:00	326:05:00	13.7	0.060685	0.978571
Function Check	Any member of Mecha	13	103:40:00	145:40:00	249:20:00	145.7	0.05635	11.20769
Inspects Part	Any member of Qualit	14	28:50:00	125:35:00	154:25:00	125.6	0.060685	8.971429
CPLM Check	FRC Manager	13	0:15:00	11:50:00	12:05:00	11.8	0.05635	0.907692
Request Part File	FRC Manager	1	0:00:00	3:00:00	3:00:00	3	0.004335	3

Resource	Unit	Cost/Unit	Threshold	Usage	Cost	#People	Utilization
FRC Manager	Hour	32.73	0	14	$458.22	1	6.42%
Any member of Machinists	Hour	25.7	0	153	$3,932.10	1	66.49%
Any member of Mechanics	Hour	24.25	0	145	$3,516.25	3	63.16%
Any member of Quality Ass	Hour	22.57	0	125	$2,821.25	1	54.44%
Any member of DLA	Hour	26.5	0	60	$1,590.00	1	27.39%

Performers Queue Length and Utilization

Name	Average	Min	Max	Utilized(%)	Idle(%)
Any member of DLA	2.75	0	18	26	74
Any member of Engineer	0	0	0	0	100
Any member of Librarian	0	0	0	0	100
Any member of Machinists	3.7	0	11	66.16	33.84
Any member of Mechanics	0.45	0	2	62.86	37.14
Any member of Quality Ass	0.12	0	1	54.19	45.81
FRC Manager	0	0	1	6.4	93.6
Generic	0	0	0	0	100
Value of 'Creator'	0	0	0	0	100

Bottlenecks

Process	Activity	Performer	Avg Queue Length	Min Queue Length	Max Queue Length
DepotMaintenanceProcess	AM Print Out	Any member of Mac	2.35	0	8
DepotMaintenanceProcess	Adjust Design	Any member of Mac	1.35	0	9
DepotMaintenanceProcess	CPLM Check	FRC Manager	0	0	1
DepotMaintenanceProcess	Function Check	Any member of Mec	0.45	0	2
DepotMaintenanceProcess	Inspects Part	Any member of Qua	0.12	0	1
DepotMaintenanceProcess	Receive Request	Any member of DLA	1.31	0	16
DepotMaintenanceProcess	Sends Rqst to Depot	Any member of DLA	1.44	0	11

Note:	Red-marked Waiting Time values indicates "Activity has waiting time"
	Red-marked Usage values indicates "Usage crossed threshold"

Figure 16. Radical To-Be Model With Additive Manufacturing and Collaborative Product Lifecycle Management

APPENDIX B. AIRCRAFT AND SHIP MAINTANANCE BUDGET

Department of the Navy
FY 2014 President's Budget Submission
Operation and Maintenance, Navy
Budget Activity: Operating Forces
Activity Group: Air Operations
Detail by Subactivity Group: Aircraft Depot Maintenance

III. Financial Summary ($ in Thousands):

A. Sub-Activity Group Total	FY 2012 Actuals	FY 2013 Budget Request	FY 2013 Congressional Amount	FY 2013 Action Percent	FY 2013 Current Estimate	FY 2014 Estimate
1. Aircraft Depot Maintenance	1,170,535	960,802	960,802	100.00	960,802 /1	915,881

B. Reconciliation Summary

	Change FY 2013/2013	Change FY 2013/2014
Baseline Funding	**960,802**	**960,802**
Congressional Adjustments (Distributed)	0	0
Congressional Adjustments (Undistributed)	0	0
Adjustments to Meet Congressional Intent	0	0
Congressional Adjustments (General Provisions)	0	0
Carryover	0	0
Subtotal Appropriation Amount	**960,802**	**0**
Overseas Contingency Operations and Disaster Supplemental Appropriations	201,912	0
Less: Overseas Contingency Operations and Disaster Supplemental Appropriations	-201,912	0
Fact-of-Life Changes (CY to CY)	0	0
Subtotal Baseline Funding	**960,802**	**0**
Reprogrammings	0	0
Price Change	0	5,380
Functional Transfers	0	0
Program Changes	0	-50,301
Current Estimate	**960,802**	**915,881**

/1 Excludes FY 2013 Overseas Contingency Operations Supplemental Funding Request

80

Exhibit OP-5, 1A5A
(Page 2 of 6)

Figure 18. FY 2014 President's Budget Submission—Operation and Maintenance (DoN, 2013a, p. 80)

Department of the Navy
FY 2014 President's Budget Submission
Operation and Maintenance, Navy
Budget Activity: Operating Forces
Activity Group: Ship Operations
Detail by Subactivity Group: Ship Maintenance

IV. Performance Criteria and Evaluation Summary Table 2 :

Activity: Non-depot / Intermediate Level Maintenance

Activity Goal: The Intermediate Maintenance program supports intermediate maintenance performed by Navy personnel and civilians on tenders, repair ships, aircraft carriers, at Regional Maintenance Centers (RMCs), Trident Refit Facilities (TRFs), and at the Naval Submarine Support Facility (NSSF) New London.

Description of Activity: The intermediate level maintenance program funds the pay of civilian personnel, materials and day-to-day operations at the RMCs, Trident Refit Facilities, and the Naval Submarine Support Facility. The RMCs perform intermediate maintenance on ships and submarines assigned to the port. The Trident Refit Facilities provide industrial support for incremental overhaul and repair of Trident submarines and for the overhaul of equipment in the Trident Planned Equipment Replacement (TRIPER) Program. Naval Submarine Support Facility (NSSF) New London provides intermediate level maintenance, ordnance, and supply support to nuclear attack submarines, support vessels and service craft.

	Prior Year (FY 2012)		Current Year (FY 2013)		Budget Year (FY 2014)	
	Budget ($ in K)	Actuals ($ in K)	Budget ($ in K)	Estimated ($ in K)		Budget ($ in K)
Labor	568,433	642,167	646,570	646,570		671,313
Material	404,172	519,186	496,109	496,109		509,649
TOTAL	972,605	1,161,353	1,142,679	1,142,679		1,180,962
	W/Y		W/Y		W/Y	
Civilian on board (Work Years (W/Y))	5,911	6,771	6,571	6,571		7,009
Qty Homeported Ships Maintained	245	247	243	243		235

Exhibit OP-5, 1B4B
(Page 6 of 9)

Figure 19. FY 2014 President's Budget Submission—Operation and Maintenance (DoN, 2013a, p. 122)

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